

MAHONING RIVER BIOTREATABILITY STUDY FINAL REPORT

JULY 2004

**FOR EASTGATE REGIONAL COUNCIL OF GOVERNMENTS AND
U.S. ARMY CORPS OF ENGINEERS – PITTSBURGH DISTRICT**

EXECUTIVE SUMMARY

This report describes the results from a biotreatability study conducted at a Test Site of the Mahoning River and an evaluation of the feasibility of using enhanced bioremediation to reduce contaminants of concern (COCs) in sediments in the river and along the banks to concentrations that would meet human health criteria established by the Ohio Environmental Protection Agency (OEPA). The report documents the activities, procedures, analyses, and findings of the treatability study. The final sections also present anticipated scenarios and costs associated with the scale up of the technology for widespread river and bank remediation.

Chemical sampling was performed at the Test Site before, during, and after the study. After the initial sampling, a consortium of indigenous microbes, specifically designed for the Test Site and the contaminants found there was applied to an area 50 by 50 feet, just upstream of the Liberty Street dam on the western shore. The study continued five months after the inoculum was applied. Based on the samples that were taken and the relatively short duration of the study, it was concluded that treatment of the bank sediments exhibited reductions in many of the major COCs, while the sediments in the river remained fairly unresponsive to treatment. Total polycyclic aromatic hydrocarbons were reduced 35.9% in the river sediments, 21.5% in the ecotone, and 92.6% in the riparian zone of the Test Site. Total pesticides were reduced 43.2% in the ecotone and 98.0% in the riparian zone, but were not reduced in the river sediments. Total petroleum hydrocarbons were not reduced in the river sediments, remained the same in the riparian zone, but were reduced 93.7% in the ecotone. Aroclor 1260, a polychlorinated biphenyl, was being transformed to breakdown aroclors in the bank sediments, while arsenic was reduced 15%, chromium 96%, and manganese 40% at the Test Site. It was concluded that the technology showed promise as a remedy for treating the contamination along the shore and near shore sediments of the river, while minimizing potential damage that could result from a more invasive remedy. Costs for treating the bank sediments in a large scale-up were estimated to be approximately \$202,000 to \$375,000 per river mile or \$4.30 to \$8.00 per cubic yard (plus or minus 30%) to treat the banks only and \$374,000 to \$694,000 per river mile at \$5.95 to \$11.00 per mile to treat both the river and banks..

SECTION 1.0 BACKGROUND AND OBJECTIVES

The Biotreatability Study project involved testing the suitability and effectiveness of using microbes as a remedy to restore Mahoning River sediment quality. The treatability study was part of a much larger and complex project to restore the quality of a 31-mile stretch of the Mahoning River from the Ohio-Pennsylvania border to the dam at Leavittsburg, Ohio.

1.1 OVERALL RESTORATION OBJECTIVES

The overall river restoration objectives are to:

“Restore the Aquatic ecosystem and biotic integrity of the Mahoning River within the project area [31 miles] to a level existing on a model reach on the Mahoning River just upstream of the project area and to eliminate the Ohio Department of Health Human Health Advisory currently in effect.” (In-Situ Biotreatability Study Statement of Work, November 25, 2002)

The Model Reach is defined as a baseline condition where the Mahoning River meets OEPA standards and is located roughly from River Mile (r.m.) 44.0 to r.m. 46.2.

1.2 PROJECT DESCRIPTION AND BACKGROUND

The Mahoning River served for years as a receiving stream for both untreated municipal wastes and industrial discharges. As a result, sediments in the river became contaminated and the aquatic ecosystem severely impacted. The larger remediation project is expected to restore the Mahoning River, within the 31-mile project area, to a fishable and swimmable stream in compliance with the Clean Water Act. Restoration could be accomplished in a number of ways. Remedial technologies currently under consideration include dredging and biotechnologies, among others.

Bioremediation is one of the remedial alternatives under consideration. Before this technology is compared to other alternatives being considered, it was tested on contaminated sediments from a Test Site to demonstrate its effectiveness on the particular combination of pollutants found there. This demonstration was conducted through performance of a treatability study at the Test Site selected by the client which is located immediately upstream of Liberty Street dam on the west bank.

There are several technical documents that were reviewed summarizing work that has been performed previously on the river. The major study regarding the Mahoning River and evaluation of the resources is *Biological and Water Quality Study of the Mahoning River Basin, OEPA Technical Report MAS/1995-12-14, May 1, 1996* for the Ohio EPA Division of Surface Water. Similar to previous surveys of 1980, 1983, and 1986, this report documents the methods and results of collecting quantitative and qualitative biological, chemical, and physical data through the study area on the Mahoning River main stream, the Beaver River, the Shenango River, Little Yankee Creek, Yankee Creek, Pymatuning Creek, and other selected tributaries. Other studies include: USACE - Pittsburgh District report *Feasibility Study on the Removal of Bank and River Bottom Sediments in the Mahoning River*, 1976; and the *Environmental Dredging Reconnaissance Report*.

In addition to the 1996 study and reports listed above, other work being conducted at the time of this biotreatability study involved the characterization of the entire 31 miles of river, both bank and river sediment material. Although those data were generated too late to be used in the design of this treatability study, they can be used to describe the river characteristics when performing a detailed design for the scale-up of the technology for the entire river.

1.3 BIOTREATABILITY STUDY OBJECTIVES

There are a number of study objectives for the Test Site biotreatability study, including the following:

- Demonstrate the technology;
- Evaluate the technology's effectiveness at the Test Site within the limits of the budget and schedule;
- Assess whether the technology can be successfully implemented on a large scale;
- Investigate the scale-up potential of the technology for the entire 31 miles of the Mahoning River in the project area or portions of the project area;
- Estimate the unit cost for full scale implementation;
- Estimate the duration of a full scale cleanup; and
- Provide data to allow the evaluation of the technology compared to other remedial alternatives.

Full remediation is considered complete when the concentrations of the Contaminants of Concern in the Test Site are at or below those concentrations found in the Model Reach, which was used as ultimate cleanup goals for the Test Site. The biotreatability of the Test Site was a pilot study of limited duration. It was not the objective of the study to fully remediate the Test Site, nor was it the objective to design and test a variety of application methods to be used in a full-scale treatment.

SECTION 2.0 DESCRIPTION OF THE TEST SITE

2.1 PHYSICAL DESCRIPTION

The Test Site is a 50 by 50-foot plot along the western bank of the Mahoning River, just upstream from the Liberty Street dam at r.m. 27. The bank at the site is fairly flat from the river's edge, but densely vegetated. The Test Site is in a quiescent pool along the river's edge, formed by pooling behind the Liberty Street dam. Visibility in the water was about two feet and the water was an olive green color.

Soils were found to consist of brown silts, sands and clays. Visible contamination was not detected in any riparian zone soils to a depth of 20 feet at the initial boring site, so the borings in the Test Site were moved approximately 10 feet closer to the river, where contamination was encountered at a depth of between 5 and 6 feet. Visible changes to soils in the ecotone were encountered at depths ranging from 3 to 5 feet. Sediments in the river were generally dark gray silts and, when disturbed, sometimes produced an oil sheen.

Figure 2-1 is a US Geological Survey (USGS) 7.5-minute quadrangle map of the area of the Test Site. Figure 2-2 is an aerial photograph of the Test Site.

2.2 CONTAMINANTS OF CONCERN

Contaminants of Concern (COCs) were identified by the client from past studies. They fell into four groups, based on health advisories. These were: total analyte list metals (TALs), particularly mercury, also referred to as leachable metals; polycyclic aromatic hydrocarbons (PAHs), also known as polynuclear aromatic hydrocarbons and semi-volatile organic hydrocarbons; polychlorinated biphenyls (PCBs), also referred to in this report by the commercial product name of aroclor; and total recoverable petroleum hydrocarbons, also referred to in this report as Total Petroleum Hydrocarbons (TPHs). Also of interest, although not particularly targeted as analytes of concern by the client, were pesticides. Pesticides were targeted by Lambda because of their potentially toxic affect on the microbial consortium to be used for the treatment.

Figure 2-1. Topographic Map of the Test Site Area

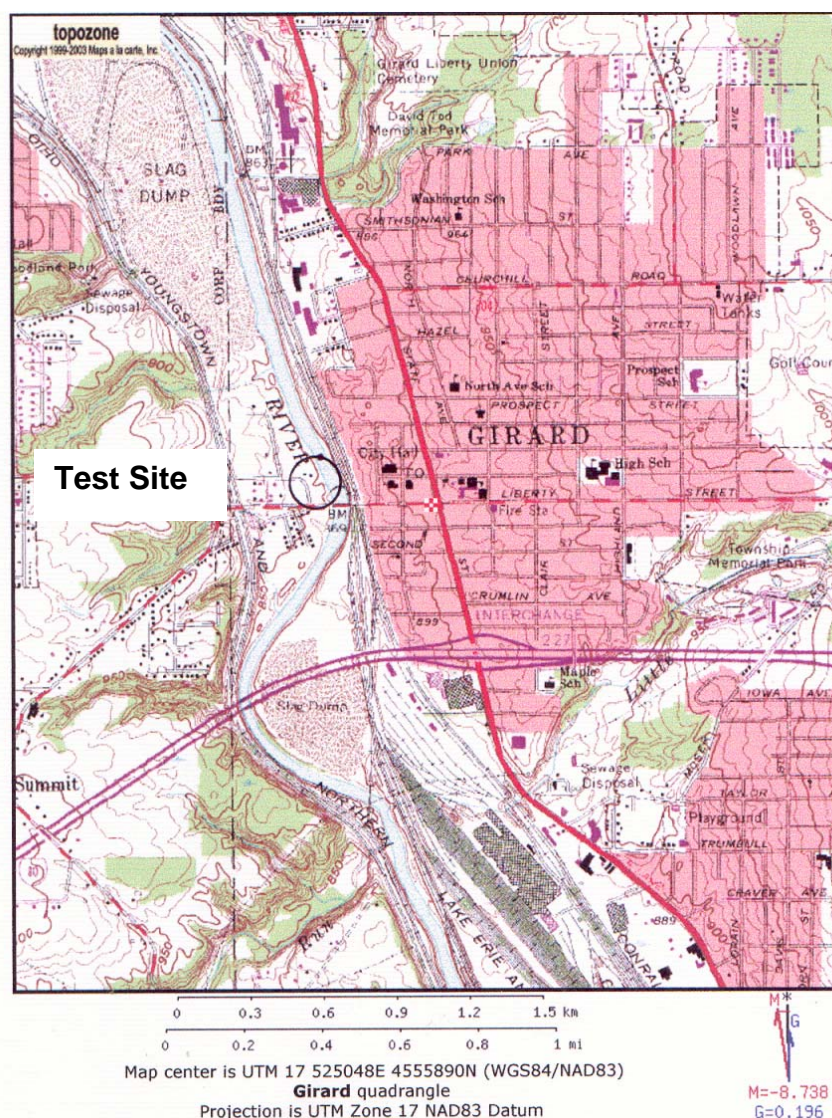


Figure 2-2. Aerial Photograph of the Test Site.



SECTION 3.0 DESCRIPTION OF THE TECHNOLOGY

3.1 ECOLOGICAL BALANCE

Enhanced bioremediation using microbial consortia indigenous to the site is a relatively unique process that is an appropriate remedy at sites having a complex site conditions (variable ecological zones, vegetation, and soils) and a complex mixture of contaminants to be addressed. Both of these criteria are met by the Mahoning River. Bioremediation is a passive technology that has the added advantage of causing minimal disturbance to the river ecosystem.

The technology is based on being able to induce nature to clean up contamination while keeping the ecosystem in balance. In this way, the forces of nature can be harnessed to assist the remediation. Site soils and sediments have a normal carrying capacity for microbes found in the naturally-occurring community. These communities differ, based on the physical and chemical setting of the site. At the Test Site, there were three communities found, representing soils that are usually saturated (river sediments), those that are sometimes saturated (ecotone), and those that are occasionally wet (riparian). When there is no contamination present, these communities thrive and create a natural chemistry. When contaminants are introduced, the communities are stressed. If the contamination is severe, many of the naturally-occurring microbes die due to the toxic effect of the pollutants. To restore the natural balance, microbes that will use the contamination as a food source can be used to treat the pollution. Simply introducing unadapted, indigenous microbes into areas of toxic contamination will only result in their death. Therefore, finding a way to use indigenous microbes that have begun to adapt to the contamination and encouraging their viability will result in the destruction or transformation of the contamination by increasing the soil's carrying capacity. Once this food source decreases to normal levels, the carrying capacity of the soils decreases and the microbial population decreases to normal levels.

Waste Science Inc. (WSI) subcontracted Lambda Bioremediation Systems, Inc. (Lambda) of Columbus, Ohio. They employed the concept of balancing the microecosystem to bioremediate the Test Site at the Mahoning River. Microbes from an area of moderate contamination (Recovering Area) were used by Lambda to fortify a microbial consortium to remediate the site. Proprietary databases were consulted to identify the microbes possessing the functions needed to transform or destroy all contamination and byproducts, transforming them into carbon dioxide and water or, in the case of metals, making them less bioavailable or less leachable. Microbes such as bacteria, fungi, protozoa, and algae are combined to work synergistically to reduce contaminant levels, destroy daughter products, and produce the supporting enzymes and adjustments that encourage full remediation.

3.2 MAHONING RIVER ECOSYSTEM

There is no more difficult ecosystem for demonstrating the potential of a technology to remediate contamination than a river. A river is a collection of ecosystems with constantly changing dynamics. This feasibility study separated the area into three basic ecosystems:

- 1) The river zone, made up of the water, the soil/water interface, an approximately 6-inch sub-soil polluted with mixed industrial waste in the sediment.
- 2) The ecotone, or flood plain ecosystem, separating the river from the riparian, or tree zone. When the river is in its normal channel, this area is dry with plants, such as jewel weed, poison ivy, stinging nettle, and tangle vine that have migrated down from the riparian zone, and some wetland plants such as sedges, Johnson grass and deer-tongue grass. When the river floods, this area is submerged. This is normally where the greatest erosion occurs, causing siltation in the river as the water recedes, reducing dissolved oxygen in the water, and increasing suspended solids that prevent sunlight from reaching the algae that need it for photosynthesis. The plant roots hold the soil in place and can further reduce erosion significantly. They also absorb pollution left behind by the receding water through their root system. This area is considered the transition zone between two major ecosystems, the river and the riparian zone. It is often the most polluted of the three zones.
- 3) The Riparian, or a tree zone, containing the primary tree, shrubs and other plant life indigenous to the area. When the river rises high enough during a flood event, river water enters this zone. Erosion potential is minimal, but pollution carried by the river remains when the water recedes. It is generally the least polluted of the three zones.

The Mahoning is one of the most polluted rivers in the state of Ohio due to the large number of industrial plants (especially steel) that have been discharging their wastes to it since the 1800's. The mixed industrial wastes contained PCBs, PAHs, TPH, heavy metals, SO₄ and some acidic drainage from their coal piles. Farm runoff, which also reaches the river, contains pesticides, herbicides and fungicides and high levels of nitrates, phosphates, potassium, trace elements and manure. Erosion and siltation from the tributaries are added by farms, barren lands and stormwater drainage discharge. Nature has the unique ability to clean surface water, soil and ground water, but over 100 years of toxic levels of COCs have killed off much of the microbial populations and imbalanced the micro ecosystem in the river and ecotone. Re-balancing the ecosystem is challenging due to the high levels of toxicity that cause toxic shock. When faced with this environmental stress, organisms can migrate away from the pollution, die or adapt. The COCs are too pervasive for migration and the microbes in areas of high stress have died off. The microbes on the fringes of the contaminated zone have been able to adapt and restore a balanced micro ecosystem in this limited area.

WSI/Lambda's challenge was to use enough adapted microbes to re-balance the system in an area of high toxicity and degrade the COCs without chemicals or genetic engineering. Previous studies by the USACE demonstrated that the highest concentrations of contaminants along any given transect were generally found at the bank of the river at the water line. The remedy was designed to provide a protected area where the microbes can reproduce over a period of time. Lambda's proprietary acclimation process was used to adapt all the microbes to work in a toxic zone.

3.3 FEASIBILITY FOR TEST SITE REMEDIATION

The contamination found at the Test Site was a complex mixture of 39 individual contaminants, including metals, oils, pesticides, PAHs, and PCBs. Superimposed on this were site variables, including pH, moisture content, oxygen levels, oils and greases, temperature, vegetation, and organic content, among others. Additionally, three distinct ecological communities were found in the Test Site, associated with river sediments, ecotone sediments, and riparian zone. Finally, variables associated with the depth of burial, seasonal changes, and river flow added to the

complex nature of the site. All of these variables had to be considered during the design of the inoculum. The complex inter-relationship of these factors is one reason that a single microbe or process cannot successfully treat the contaminants at the site.

The most difficult part of this work was to custom design a healthy microbial ecosystem, made up of multiple balanced mini-ecosystems to degrade all of the COC's and their toxic "daughter products. PCB's are exceedingly complex and require multiple microbes in multiple combinations. The microbes had to be a large consortium that do multiple jobs; reductive dehalogenation, synergistic systems, co-metabolism, methanogenic, etc., with aerobic, facultative anaerobic and methanogenic microbes fungus, algae, protozoan and multiple enzymes, vitamin mixes, co-enzymes and the proper nutrient balance.

Lambda has a database of over 15,000 microbes that was used to identify all the microbes needed and their nutrient, enzyme, etc., requirements. Lambda's processes for remediating the site are proprietary. However, this report presents an illustration of the steps needed to design the consortium, using the destruction of PCBs as an example. Although not as complex, similar processes are needed for the destruction or transformation of all of the other contaminants at the site, as well.

PCBs are synthetic, oily aromatic compounds that contain two benzene nuclei with two or more substituent chlorine atoms. (Condensed Chemical Dictionary, Tenth edition, Gessner G. Hawley, 1981). Their industrial trade name is aroclor and their manufacture was stopped in the United States in 1977, but their presence in the

Bio-Degradation of PCBs

The degree of chlorination in PCBs defines both the properties and the industrial application of PCB commercial products. All 209 individual chlorinated biphenyls are referred to as PCB congeners. Each congener has a unique molecular structure. Aroclors are highly complex mixtures of PCB congeners. PCB isomers are congeners with the same number of chlorine atoms. Chlorobiphenyls break down into chlorine (that is sorbed) and biphenyls by co-metabolism and reductive dehalogenation. The chlorinated ethenes and ethanes forms convert to methane, then carbon dioxide and water. Biphenyls split into phenolic compounds, benzene, and cumene. Benzene breaks down aerobically into pyrocatechol, a highly toxic compound, that is part of the breakdown by deoxygenase-catalyzed oxidation, dehydrogenation oxidative meta-ring cleavage. The synergism of the consortium breaks pyrocatechol into methane. Methanogenic bacteria, using hydrogen as an energy source, break the pyrocatechols into carbon dioxide and water. PCB congeners substituted in at least two meta and para positions are the most effective inducers of cytochrome P448-dependent mono-oxygenases (enzymes necessary for the degradation of PCBs). As the degree of biphenol chlorination increases, their rates of metabolism decreases.

The composition of PCBs in environmental samples is markedly different from commercial mixtures due to their variable physical and chemical properties.

The ultimate breakdown of PCBs in the environment will depend on a multitude of factors, including microbial action. It has become important to evaluate the effects of microorganisms on both individual PCB isomers and congeners and the commercial formulations.

The microbial scheme for biphenol metabolism is consistent with the breakdown of other aromatic hydrocarbons and clearly suggests routes for the metabolism of PCBs. Tests from activated sludge (aerated) soils and river water all reported similar activity in tests over five, 10, and 15 days. Maximum degradation occurred within the first five days. In addition, similar results were obtained by the co-metabolism of PCBs and acetate by mixed cultures (consortia).

environment is still fairly ubiquitous. Aroclors have numbers associated with them that indicate their chemical composition and weight. Aroclor 1260, for example, is a heavy aroclor and the "60" indicates a mixture that contains approximately 60 percent chlorine by weight. PCBs do not readily break down in the environment, and aroclors containing more chlorine atoms (heavier) are more resistant to degradation than the lighter aroclors. They can be present in the environment as solids, liquids, or gases and can cycle between adsorption onto soil particles and evaporation into the atmosphere, to be re-deposited at another location. Heavier PCBs tend to sink into water and adsorb onto particulates, while lighter PCBs are more likely to migrate through evaporation.

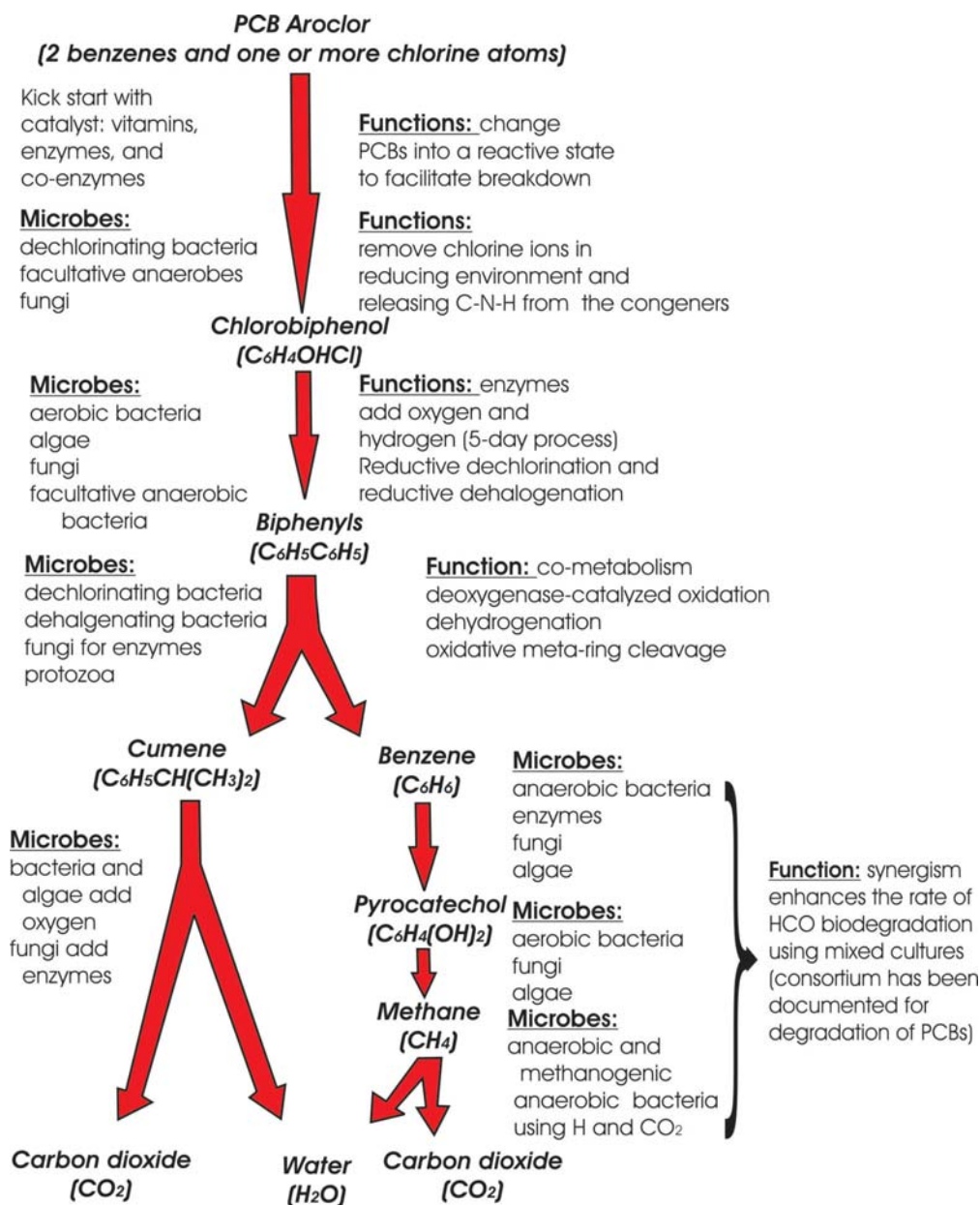
The process to bioremediate PCBs was researched as part of this project. It was found that PCBs require a 35-step process for their destruction from the heaviest aroclor (1260) into carbon dioxide and water. Over 50 individual microbes are required to complete the process. Figure 3-1 illustrates the basic process involved in the destruction of aroclor 1260. The process is similar for lighter aroclors. In fact, as chlorine atoms are stripped from the biphenyls, lighter aroclors are temporarily created. Figure 3-1 also shows that different microbes become active at different points in the process and that certain functions occur under aerobic (oxygen-rich) conditions while other take place under anaerobic (oxygen-depleted) conditions. These conditions are created by the bacteria themselves and do not have to be imposed by further stressing the system (e.g., by injecting oxygen). Certain by-products are created during this process, including both toxic compounds and some relatively benign products. All of these products will eventually be destroyed and the microbes will continue to work as long as there is sufficient fuel (contamination) to feed them.

Facultative anaerobic bacteria carry on reductive dechlorination and, along with fungal-produced enzymes, remove chlorine ions and adsorb the chlorine onto soil particles while releasing carbon and hydrogen from the congeners. The carbon is a food source for the microbes in the next degradation step and the hydrogen is used in the methanogenic stage as the energy producer. (Adsorbed materials are more amenable to biodegradation.)

SECTION 4.0 QUALITY ASSURANCE AND QUALITY CONTROL

A Quality Assurance Project Plan (QAPP) and Field Sampling Plan (FSP) were used during this project to define quality objectives and provide the protocols and means for accomplishing these objectives. GPL Laboratories of Frederick, Maryland and Severn Trent Laboratory of Pittsburgh, Pennsylvania were used to perform chemical analyses on samples from the site. Both laboratories are certified by the USACE and other federal agencies for the analyses that were performed on the samples. Ten percent of the samples were split between the two laboratories, as required in the FSP. Duplicate samples were collected to allow matrix spike/matrix spike duplicate analysis. A discussion of the chemical analytical QA results is found in Section 7.1.4 of this report. The reader is referred to the QAPP (G-221-RD-02, rev.01, May 21, 2003) and FSP (G-221-RD-06, rev.02, November, 2003) for a full discussion of the quality measures employed during this work.

Upon receipt from the laboratory, data packages were validated using criteria in the statements of work, the analytical methods, the organic and inorganic EPA *Functional Guidelines for Data Validation*, and guidance from the US Army Corps of Engineers. Data quality checks performed included the following checks:

Figure 3-1 – Schematic of Bioremediation of PCB Aroclors

- Sample preservation and holding time
- Instrument performance criteria (GC column resolution and breakdown checks, for example)
- Initial and continuing calibration checks
- Blank checks for contamination
- Laboratory Control Samples
- Matrix Spike Samples
- Duplicate Samples
- Method-specific QC Checks (e.g. ICP interference check samples for metals analyses)
- Confirmation of instrument sensitivity and checks for analytical interferences

The data were qualified where deficiencies in data quality were found, as discussed in Section 71.4. Field quality control before performing field measurements consisted of instrument calibration and checking of standard solutions (e.g. pH buffers) before performing measurements. Details of these procedures are provided in the QCP.

As required in the Scope of Work, review comments on the draft plans are included as Appendix F, and review comments on the Draft Final Report are included as Appendix G in this report. All original data sheets regarding laboratory results and the QA/QC backup was provided to the clients in a separate package and on compact disk. Copies of field notes and data sheets are included as Appendix C.

SECTION 5.0 HEALTH AND SAFETY

Health and safety was conducted in accordance with the Safety and Health Plan, dated May 21, 2003. The reader is referred to this document for the details of the health and safety procedures used for this study (G-221-RD-04 rev. 01). Organic vapor monitoring conducted during the initial sampling event allowed the Site Safety Officer to discontinue this portion of the program for the remaining sampling events.

SECTION 6.0 FIELD SAMPLING

The sampling program evaluated the chemical and biological quality of contaminated sediments before, during, and upon completion of the field biotreatability study. Samples were collected at three times during the study: 1) initial sampling established chemical and microbial baseline information performed May 31 through June 1, 2003, 2) interim sampling was conducted six weeks after inoculation on November 6, 2003, and 3) final sampling was conducted at the study is conclusion (March 27 and 28, 2004).

Initial field samples were collected from three sites:

- Model Reach Site representing baseline conditions and establishing cleanup goals where environmental quality of the Mahoning River meets the OEPA Warm Water

Habitat (WWH) conditions. A site was selected in Leavittsburg, PA; along the left bank at the Levitt Highway Bridge. (r.m. 46.2)

- Recovering Area Site where contamination is moderate, such that existing microbes are somewhat acclimated to the contamination and some degree of biotic recovery has occurred. A site was selected at Packard Park, along the left bank 90 feet downstream of the footbridge. (r.m. 41)
- Test Site where large deposits of highly contaminated sediments have accumulated behind the low head Liberty Street Dam in Girard, Ohio. The USACE selected the western bank approximately 150 feet upstream of the dam. (r.m. 27)

Specific locations of the other two sampling sites were selected in discussions among WSI, Eastgate, and USACE, based on considerations such as anticipated contamination conditions, physical accessibility, and access rights. Locations were finalized in the field. At each site, samples of contaminated sediments were collected from three zones:

- River sediments within a zone extending approximately 16 feet from the water's edge into the river. The contaminated sediments are present at or very near the water-sediment interface in this zone.
- Ecotone sediments within a transition zone extending from the water's edge to approximately 17 feet up the bank. The top of contaminated sediments in this transition zone were expected to be within two to three feet below ground surface, and the thickness of the sediments was expected to be more than six feet.
- Riparian sediments within an area approximately 17 to 34 feet from the water's edge. The sediments of interest for this study were typically about three feet below ground surface and below the water table at approximately six feet.

6.1 INITIAL SAMPLING DESIGN

Initial sampling was designed to obtain samples most representative of pre-treatment site conditions within three ecological zones. By sampling these three settings at three locations (Model Reach, Recovering, and Test Site locations), we were able to provide a preliminary quantification of the concentrations of the COCs, site chemistries, and microbial communities exposed to varying degrees of contamination. This was used to assess system performance under varying levels of stress and toxicity. Sampling locations for all sampling events are shown in Figure 6-1¹. Initial samples end in "05."

At each location where a river sample was collected, a sample of river water also was collected for field analysis and limited chemical laboratory analysis. Individual sampling locations were used, but the sample at each discrete location was composited over a depth range. For example, if the investigation found that contamination was present (based on historical records, current data, visual evidence, textural evidence, or smell) at depths ranging from two to four feet in a particular sample, the soil was collected over that entire depth and homogenized before being placed into sample containers. Although this type of compositing tends to average the concentration over the entire depth and could dilute certain hot spots, it is an acceptable method for ensuring that the

¹ In advance of collection of any samples, locations of underground utilities at each site were identified by notifying the Ohio Utility Protection Service at 800-362-2754. No underground utilities were present at any of the three sampling sites.

entire contaminated depth is represented by a single sample. This technique is often used when a limited number of samples are budgeted to characterize the chemistry of a site.

6.1.1 Model Reach and Recovering Area Sites

At the Model Reach and Recovering Area sites, a representative sediment sample was collected from each of the three zones (river, ecotone, and riparian) along a 50-ft length perpendicular to the river, for a total of six sediment samples. (See Figures B-1 and B-2 in Appendix B.) Sample depths in the river sediments extended from zero to one foot, in the ecotone from 4 to 5 feet, and in the riparian zone from 5 to 6 feet. To stay within the budget allotted for sampling, only one sample from each zone at these two sites could be collected. Because Model Reach concentrations have previously been established and because the Recovering Area was sampled primarily for biological reasons, a more extensive sampling of these two sites was not a priority.

6.1.2 Test Site

At the Test Site, the sampling plot 50 by 50 feet was subdivided into the three zones of interest (river, ecotone, and riparian), similar to that of the Model Reach and Recovering Area. Transects were located so approximately one-third of the sampling plot extended into the river, as illustrated in Figure 6-1.

Locations were staked in the field at the time of sampling, referenced to existing site features. The samples were collected from approximately the mid-point of each zone along the entire 50-ft alignment. The river sediment sample transect was located approximately eight feet into the river from the water's edge (as defined during the May 31, 2003 sampling date); the ecotone sample transect was located approximately eight feet up the bank from the water's edge; and the riparian sample transect was approximately 25 feet up the bank from the water's edge. The initial sample location for the riparian samples had to be moved closer to the river, as no visible contamination was detected at the first location to a depth of eight feet. As a result, the entire Test Site plot was shifted slightly eastward. Figure 6-1 shows the shifted boundaries of the site and the sample locations. Location TRM05 is shown as being beyond the shifted boundaries for this reason. Later riparian samples corrected for this condition. Because the Model Reach and Recovering Area sites were sampled only once, during the initial sampling event, location reference markings were not left at those sites.

Samples were collected along the center alignment, one sample in each zone, for a total of three samples during each event. A river water sample also was collected at the Test Site during the initial sampling event. Field analysis and limited chemical analysis of the water sample (listed in Table 6-1) characterized the environmental conditions under which the microbial consortium must survive and thrive after inoculation is performed. Because the river level and therefore the location of the water's edge varied somewhat between the initial and subsequent events, the sampling plot was based on the location of the water's edge during the initial sampling (May 31, 2003).

The depth target for sampling was the mid-point of the contaminated layer in each zone. The depth range of the contaminated zone was based on professional judgment and historical chemistry, along with field measurements and observation. Therefore, initial samples were collected at the following depths at the Test Site:

- Zero to six inches in the river zone
- Three to four feet in the ecotone zone

- Four to six feet in the riparian zone.

Samples were composited over the sampling depth in each hole to better represent the average vertical distribution of contamination. Each boring in the ecotone and riparian zones was extended during the initial sampling event to verify the bottom of the contaminated layer or to a maximum depth of 12 feet, but no additional samples were collected deeper than indicated in the list above. Samples were collected using either a stainless steel trowel or a closed-bucket hand auger. Samples of river water were collected in hand-held bottles. All samples were grab samples.

6.2 SIX WEEK (INTERIM) SAMPLING

Sampling was performed six week after the Test Site was inoculated. Three samples were collected during the six-week sampling event, as shown in Figure 6-1. These interim samples exhibit labels that end in "11." The purpose of this sampling was to monitor the progress of the remediation in a limited area. As a result, samples only were collected from the ecotone zone of the Test Site. Stakes were installed in the field to mark the initial sampling locations so interim samples could be collected from the same hole, or within one foot of the initial sampling location. Samples were collected from as close to the injection points as possible. This was done because: 1) the injection points generally were close to the initial sampling points, so direct comparisons between data taken on different dates could be facilitates, and 2) it was presumed that the duration of the study was not long enough to allow for the microbes to migrate far beyond the point of injection. The results of the interim sampling were used to judge whether re-inoculation was necessary. If no difference had been detected between initial and interim sample concentrations, the inoculum formulation would have been adjusted and the site re-inoculated. This was not necessary.

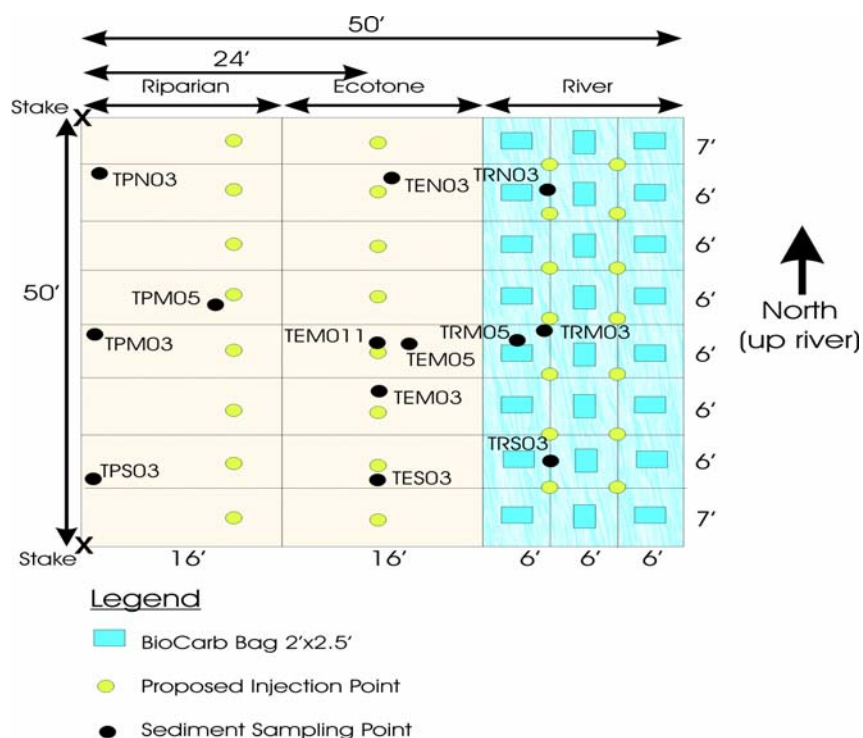
Sample preservation, packaging, and shipping was similar to the initial sampling. However, the interim samples were not subjected to quality assurance/quality control splits and a more limited set of analyses was performed. Only the middle sample of the Test Site ecotone (TEM011) had a nearly comprehensive list of analyses performed, including: PCBs, PAHs, manganese and zinc TCLP, ferrous and ferric iron, potassium, ammonia, nitrate, nitrite, TKN, oil and grease, salinity, total phosphorus, sulfate, TPH, and TOC. The comprehensive sampling results, along with the analytical methods used for the interim sampling are presented in Appendix A, and the COCs are summarized in Tables 7-2 through 7-7 in Section 7 of this report.

6.3 FINAL SAMPLING

A final round of samples was collected five months after site inoculation to monitor the progress of the Test Site remediation. The same analytes (excluding salinity) were analyzed in the final sampling as were analyzed in the initial sampling. The same protocol was used for sample collection and preservation, packaging, and shipping. QA/QC samples were again collected and analyzed by Severn Trent Laboratory. There was a slight adjustment to the locations of the riparian samples during the final sampling. Final sampling locations are shown in Figure 6-1, with labels that end in "03."

6.4 FIELD MEASUREMENTS

Table 6-1 presents the results of the field measurements that were taken during the sampling events. It should be noted that volatile organic compound measurements were collected during the

Figure 6-1. All Sampling Locations**Table 6-1. Field Measurements Taken During Sampling at Test Site**

Field Measurements	Initial Sampling			
	Water	River M	Ecoto ne M	Riparian M
pH (pH units)	5.48	5.6	5.63	5.5
Methane (CH ₄)	0	0	0	0
Redox Potential (millivolts)	221	217	206	213
Temperature (degrees C)	17.3	16.8	14.7	13.1
Dissolved Oxygen (mg/L) In River or Ground water	1.95	9.3	9.0	10
O ₂ in percent		20.0	20.7	20.9
Hydrogen Sulfide (mg/L)	0	1	0	0
Field Measurements	Interim Six-Week Sampling			
pH (pH units)	7.86	7.57	7.11	7.25
Methane (CH ₄)	0	0	0	0
Redox Potential (mill volts)	31.5	-452	-232.6	102.8
Temperature (degrees C)	11.3	10.5	15.2	13.0
O ₂ in percent		20.9	21.0	21.0
Hydrogen Sulfide (mg/L)	0	0	0	0

Final Sampling									
Field Measurements	River N	River M	River S	Ecotone N	Ecotone M	Ecotone S	Riparian N	Riparian M	Riparian S
pH (pH units)	7.24	7.14	7.02	6.83	6.89	6.55	6.76	6.61	6.83
Methane (CH ₄)	0	0	0	0	0	0	0	0	0
Redox Potential (millivolts)	-6.8	-2.3	-1.9	12.7	7.2	24.6	16.7	14.4	12.5
Temperature (degrees C)	10.0	9.6	10.9	13.8	12.6	11.8	13.5	14.3	12.3
O ₂ in percent	21.1	21.1	21.3	21.3	21.3	21.4	21.2	21.3	21.4
Hydrogen Sulfide (mg/L)	0	0	0	0	0	0	0	0	0

Note: Water – river water sample and N – M – S – North, Middle, or South initial sampling as required in the SAHP, but were determined by the field safety officer to be unnecessary during the interim and final sampling events, as none were detected.

SECTION 7.0 LABORATORY TESTING

7.1 CHEMICAL ANALYSES

Chemical analyses were performed on the samples for several reasons. First, a baseline was established in the Test Site by sampling the river, ecotone, and riparian zones. The Recovering area was sampled to compare the microbial communities in the river, ecotone, and riparian zones with that of the Test Site, in light of the chemistries. Finally, The Model Reach was sampled to establish the concentration targets of the COCs in the river, ecotone, and riparian zones.

The chemical analyses were performed by GPL Laboratories of Frederick, Maryland. The QA/QC samples were sent to USACE-approved Severn Trent Laboratory in Pittsburgh, Pennsylvania.

7.1.1 Laboratory Methods and Protocol

A complete data set is included in Appendix A. This Appendix shows the analytes and the analytical methods that were applied by the two laboratories. Although there were slight differences in some of the methods, the overwhelming majority of the analyses were performed using the same methods and resulting in the identical analytes. In some of the more contaminated samples, dilution was necessary to perform the analyses. Table 7-1 identifies the data qualifiers that are applicable to each flagged result. These qualifiers must be considered during the analysis of the data, as some values are estimates and some are indicative of the accuracy and precision of the analyses. It should be noted that any results with a qualifier flag should be judged with caution. This will be addressed further in discussions of different types of contaminants.

7.1.2 Summary of Findings

The following general statements can be made about the reductions in pesticides and PAHs, those analytes whose totals can be quantified over time.

Table 7-1. Total PAH, Pesticide, and TPH Reductions

Location of Samples	Initial Sample (ug/kg)	Interim Sample (ug/kg)	Final Sample (ug/kg)	Total Reduction Between Initial and Final
Total PAHs				
River	18190		11555	35.9%
Ecotone	28670	7352	22519	21.5%
Riparian	108298		8026	92.6%
Total Pesticides				

Location of Samples	Initial Sample (ug/kg)	Interim Sample (ug/kg)	Final Sample (ug/kg)	Total Reduction Between Initial and Final
River	51.6		99	none
Ecotone	68.6		39	43.2%
Riparian	50		1	98.0%
Total Petroleum Hydrocarbons				
River	590		2353	none
Ecotone	20000	330	1260	93.7%
Riparian	44		46	none

Tables 7-3 through 7-8 are summaries of all of the analytes that were detected in at least one sample during any of the sampling events. These tables are presented at the end of the discussions in Section 7.1.3. Samples that exhibited all results below quantitation limits for a particular analyte are not shown in these summary tables, but can be found in Appendix A, the comprehensive data table. The tables are organized to show the sample number, river location (Model Reach or Test Site), zone location (riparian, ecotone, or river zones), date of the sample

Table 7-2. Data Qualifier Definitions and Significance

Qualifier	Definition	Significance
U	Indicates that the compound was analyzed for but not detected above the quantitation limits	The compound is not present at or above the indicated concentration - Analyte is presumed to be absent or not detected at this concentration. The associated numerical value is the sample quantitation limit. The sample quantitation limit must be corrected for dilution. For a soil/sediment sample, the value must also be corrected for percent moisture.
UJ	The analyte was analyzed for, but was not detected.	The sample quantitation limit is an estimated quantity.
BQL	Below Quantitation Limit	The compound is not present at or above the indicated concentration - Analyte may be present, (that is, it may be below the Quantitation Limit but above the Method Detection Limit), but can't be accurately measured and reported.
Qualifier – Organics		
D or DL	Indicates that the analyte was reported from a diluted analysis	A loss of precision may occur with sample dilution - Original concentration was much higher. Dilution based on the concentration of the largest analyte may cause other analytes of lesser concentration to be diluted below reporting limits. This flag alerts data users that any discrepancies between the concentrations reported may be due to dilution of the sample or extract.
E	Indicates that the concentration detected exceeded the calibration range of the instrument	Since the concentration is higher than the calibrated range of the instrument, the result is an estimated concentration - The sample should have been diluted and run again, unless no portion remained for re-analysis.
J	Value is less than the reporting limit but greater than the Method Detection Limit	The concentration reported is an estimated amount due to the inherently poorer precision of data near the MDL - The analyte is present but the value is an estimate, usually 1/2 or more of the reporting limit. This flag is used either when estimating a concentration for tentatively identified compounds (TICs) where a 1:1

Qualifier	Definition	Significance
		response is assumed, or when the mass spectral data indicates the presence of a compound that meets the identification criteria, but the result is less than the sample quantitation limit but greater than zero.
P	Indicates that there is greater than 25% difference for the detected pesticide/arochlor results between the two GC columns	<i>The concentration reported should be considered an estimated value due to poor measurement precision</i> - Identification may be confirmed, but quantitation is suspect (due to possible interferences or instrument error).
Qualifier – Metals		
E	Indicates that the reported value is estimated because of the possible presence of interference (i.e., the serial dilution was not within control limits)	<i>The result may be biased high or low, and should be taken as an estimated concentration due to positive or negative interference.</i>
H	Indicates that the element was found in the associated blank as well as in the sample and the value is greater than or equal to the reporting limit	<i>The reported concentration might be biased high, or might be a false positive result, due to possible sample contamination</i> - Indicates contamination of associated samples (use various types of blanks to help identify source as field, shipment, storage, preparation or analysis stage). If an analyte is found in a blank, but <u>not</u> found in the sample, no action is taken. Positive sample results should be reported unless the concentration of the compound in the sample is less than or equal to 10 times (10x) the amount in any blank for the common phthalate contaminants, or 5 times the amount for other compounds. The results must <u>not</u> be corrected by subtracting any blank value. Any analyte that was also detected in any associated blank, is qualified if the sample concentration is less than five times (5x) the blank concentration. Typically, the sample Reporting Limit is elevated to the concentration found in the sample.
N	Spiked sample recovery not within control limits	<i>The result may be biased high or low, and should be taken as an estimated concentration</i> - Spiked analyte concentrations were not recovered with in the 75%-125% range for metal analytes, indicating a possible interference in the sample's matrix. Associated samples of the same matrix may have similar positive or negative bias.
*	Duplicate analysis not within control limits	<i>The concentration reported is an estimated amount due to poor precision</i> – Unacceptable precision may be due to non-homogeneous samples or aliquots used for testing.
R	Unusable data	<i>Data are considered unusable/unreliable based on the results of the data validation and/or field procedures evaluation.</i>

was collected (6/1/03 – initial sampling, 11/6/03 – six week sampling, and 3/27/04 - final sampling), the analyte, the result, units of measure (micrograms or milligrams per kilogram for sediments and micrograms or milligrams per liter for water and extracts), data qualifiers, and detection or quantitation limits. The tables are generally sorted by group (pesticide, metal, etc.), analyte, zone location, river location, and finally date. The labeling protocol is standardized throughout. Sample numbers that begin with “M” denote Model Reach, “R” Recovering Area, and “T” from the Test Site. The second letter denotes the zone where the sample was obtained – “E” for ecotone, “R” for river, and “P” for riparian zone. The third letter denotes where within

each zone the sample was obtained. Most samples from the Model Reach and Recovering Area were taken from the middle of the site, hence are shown as an "M". In the Test Site, samples were taken from the north, middle and southern portions of the zone, denoted as "N", "M", and "S", respectively. The sample numbers correspond to the month of the sampling event (6, 11, and 3). Other letters that follow the sample number indicate special categories, such as DL (diluted sample), DUP (duplicate sample), RE (re-analysis), MS (matrix spike), and MSD (matrix spike duplicate).

In most instances, results from the Recovering Area are not included in the tables in Section 7. Recovering Area data are presented in Appendix A. The tables in Section 7 are used only to compare the pre-treatment versus post-treatment result at the Test Site, and to compare the post-treatment results to the cleanup targets established in the Model Reach. These tables and associated discussions present only the summarized results of the sampling and do not include analytes that were not detected. Conclusions drawn from the data, trend analyses, and measures of success of the technology are presented in Section 9 of this report.

General Chemistry- The general chemistry results are indicators of the changes to the Test Site chemistry over time. These constituents are not COCs, but indicate the general health and composition of the sediments. Trends are useful to the biologist trying to ascertain the health of the ecosystem and the effect of the inoculum on the site. Many of these constituents must be measured in the field, as changes in temperature or chemical transformation over the time it takes for samples to reach the laboratory would significantly change their values. Those that were measured in the field are presented in Table 6-1.

Total Organic Carbon is the total mass of living and dead macro- and micro-organisms and COCs that contain carbon. REDOX (oxidation-reduction potential) indicates whether the site is aerobic (greater than +150 millivolts) or anaerobic (less than +100 millivolts). The pH indicates if the site is acidic (1 to 5.9), neutral (6 to 7.9) or basic (8 to 11). The Total Organic Nitrogen (TON), Total organic Phosphate (TOP), and potassium (K) are the nutrient availability of the site. Nitrate (NO₃), nitrite (NO₂), sulfate (SO₄), carbon dioxide (CO₂), and dissolved oxygen (DO) are the sources for the electrons that are available for energy. The more information we have about the environment the microbes have to work in, the more accurately we can produce the scale-up materials to achieve Model Reach conditions at the Test Site.

Most of the results for the general chemistry performed in the laboratory are unflagged, with the general exception of ferrous iron, nitrate/nitrite, and oil and grease, some of which are shown with a "U" qualifier, which means that they were below the detection limit (BQL). One sulfate sample (REM05 DUP) was flagged showing that sulfate was detected in the blank sample as well. A summary of the general chemistry is presented in Table 6-2. (Complete chemistry is presented in Appendix A.)

Oil/Grease and Total Petroleum Hydrocarbons (TPH) - Table 7-4 presents a summary of detected oil & grease and Total Petroleum Hydrocarbons (TPH). Oil and grease was not detected in samples collected in the Model Reach, but both constituents were detected in all but one sample (TES03) taken in the Test Site. TPH concentration in sediments varied widely, from 20,000 to single digit mg/kg in the Test Site ecotone. Three Oil & Grease water samples also were collected, one in the Model Reach (5.10 mg/L), one initial sample in the Test Site (6.5 mg/L), and one during the final round of sampling in the Test Site (5.7 mg/L). No appreciable difference in these results was found.

Polychlorinated Biphenyls (PCBs) - Table 7-5 presents the results of sampling for polychlorinated biphenyls (PCBs) and presents all sample locations for which at least one result exceeded the detection limit (quantitation limit). PCBs are COCs at the site. There are seven arochlors that were analyzed in the samples. Initial samples exhibited only the heaviest arochlor, 1260, present in all zones of the Test Site, but primarily in the ecotone. Arochlor 1016, 1221, 1232, 1242, 1248, and 1254 are not present at the beginning of the study. One sample was taken during the six-week sampling event and exhibited a decrease from 150 ug/kg to 34 ug/kg in the ecotone of the Test Site for arochlor 1260. The final round of samples, taken five months after treatment, shows two new arochlors, 1232 and 1254, present river sediments, and arochlor 1260 in all three zones of the Test Site. The concentrations of arochlor 1232 in the Test Site river sediments ranged from 1100 to 3700 ug/kg, post-treatment. The results flagged with "P" or "J" qualifiers are estimated concentrations.

Pesticides - Table 7-6 presents the results of sampling for pesticides at the site. Pesticides were not considered COCs in this study, although it was thought that pesticides might have been used upstream and could have found their way into sediments along the river. Table 7-5 presents all pesticides where at least one detectable result was exhibited. It can be seen that, with the exception of 4,4'-DDT (37, 36, 87, and 76 ug/kg) and methoxychlor (30 ug/kg), all other pesticides detections were below 20 ug/kg. Of the pesticides detected, the following were detected only at concentrations that were flagged at either below or very near the detection limit: 4,4'-DDE, alpha-BHC, alpha-chlordane, beta-BHC, endosulfan sulfate, endrin, and gamma-chlordane. Of the remaining detections, only the following were detected without a qualifier flag associated with the results:

4,4'-DDD	7.6 ug/kg	Ecotone Test Site	Final Sample Event
4,4'-DDT	37 ug/kg	Ecotone Test Site	Final Sample Event
4,4'-DDT	14 ug/kg	Ecotone Test Site	Final Sample Event
4,4'-DDT	36 ug/kg	River Test Site	Final Sample Event
4,4'-DDT	87 ug/kg	River Test Site	Final Sample Event
4,4'-DDT	76 ug/kg	River Test Site	Final Sample Event

Leachable Metals - Table 7-7 presents the results of sampling for RCRA-listed metals. A Toxicity Characteristic Leaching Procedure (TCLP) was performed on all samples. Seven of the 12 metals in the analyses (As, Ba, Cd, Cr, Pb, Hg, and Se) are used to determine whether a material is a characteristic hazardous waste or not. Of the 12 metals tested, only eight were found at concentrations above detection limits. These are shown in Table 7-7 below. None were found at concentrations within two orders of magnitude of what would make them a Resource Conservation and Recovery Act (RCRA) characteristic hazardous waste.

The metal found in the highest concentrations was iron, ranging from below 1500 to 1,210,000 ug/L. This is probably the result of high total ferric iron concentrations, as shown in Table 7-2. Leachable manganese was detected in every sample, ranging from 307 to 21,500 ug/L. Selenium and arsenic were found in single samples at 110 and 170 ug/L, respectively. With the exception of zinc, most other leachable metals were found in the ecotone and river zones, but not in the riparian zone.

Polycyclic Aromatic Hydrocarbons (PAHs) - Table 7-8 presents the results of sampling for polynuclear aromatic hydrocarbons (PAHs). Sixteen PAHs were detected in at least one sample of sediments at the Test Site. These included acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene,

fluorine, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene. Of these, all compounds but dibenz(a,h)anthracene (which was not detected in the riparian zone of the Test Site) were detected in the riparian, ecotone, and river sediments at every Test Site location sampled. None were detected in the Model Reach sediments.

7.1.3 Analytical Data Quality Discussion

Based on the information provided in summary tables and case narratives from both laboratories, there were matrix interferences that required dilutions in samples, including MS/MSD samples, for some parameters. Some of the aroclor peaks are known to appear at or very near the same retention times as key peaks for the DDT/DDE/DDD, possibly resulting in mis-identification and/or mis-quantitation in the 8081A pesticide method. The aroclor method, 8082, has a process step to eliminate or reduce the presence of chlorinated pesticides, so the reverse interference (DDT, etc. looking like PCB peaks) shouldn't occur. Also, based on interferences and aroclor weathering, it is possible that some of the key indicator peaks for the aroclors may have been changed (sizes and ratios) so that the identification of individual aroclors is less accurate. The 1260 peak at the end of the gas chromatograph (GC) run is distinctive, but if it is reduced in size or the GC chromatography is poor, it may be missed, and the analyte identified as 1254 instead, since they share many of the same key peaks.

Reviewing QC data presented in summary tables for the split samples analyzed at GPL and STL, each lab's internal QC results were correctly stated in their Case Narrative reports. As noted above, sample matrix interferences required dilutions in both labs. When the effects of the dilutions are considered together with the values and reporting limits for the labs, the results reported are reasonably close (generally within a factor of 2). One lab may have reported estimated hits below the reporting limit, while the other lab may not have reported an estimated hit at a somewhat higher reporting limit, based on dilutions and sample quantities analyzed. WSI drew conclusions only about results above reporting limits. One can make inferences on results below these levels, but with less certainty. In short, the QC and split sample results indicate that the results reported for associated samples were correctly analyzed, reviewed, qualified, and reported.

Table 7-3. General Chemistry Summary

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result
MEM05	Model	Ecotone	6/1/03	% Solids	80%
MPM05	Model	Riparian	6/1/03		81%
MRM05	Model	River	6/1/03		73%
TEM05	Test Site	Ecotone	6/1/03		54%
TEM11			11/6/03		56%
TEM03			3/27/04		50%
TEN03			3/27/04		53%
TEM03 DUP			3/27/04		53.9%
TES03			3/27/04		54%
TPM05	Test Site	Riparian	6/1/03		74%
TPM11			11/6/03		66%
TPN03			3/27/04		68%
TPM03			3/27/04		77%

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result
TPS03			3/27/04		80%
TRM05	Test Site	River	6/1/03		32%
TRM11			11/6/03		38%
TRM03			3/27/04		41%
TRS03			3/27/04		45%
TRN03			3/27/04		48%

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (mg/kg)	Qualifiers	Detection Limit (mg/kg)
MEM05	Model	Ecotone	6/1/03	Ammonia (as N)	BQL		3.9
TEM05	Test Site		6/1/03		18		5.5
TEM11			11/6/03		21		4.9
TES03			3/27/04		22		5.9
TEM03			3/27/04		32		6.1
TEN03			3/27/04		55		5.6
TEM03 DUP			3/27/04		71.2		9.3
MPM05	Model	Riparian	6/1/03	Ammonia (as N)	BQL		3.4
TPM05	Test Site		6/1/03		9.50		4.4
TPM11			11/6/03		5		4.1
TPS03			3/27/04		4		3.7
TPM03			3/27/04		13		4.1
TPN03			3/27/04		39		4.0
MRM05	Model	River	6/1/03	Ammonia (as N)	4.30		3.7
TRM05	Test Site		6/1/03		150		9.7
TRM11			11/6/03		57		7.0
TRS03			3/27/04		72		5.9
TRM03			3/27/04		170		8.1
MEM05	Model	Ecotone	6/1/03	Ferric Iron	15000		5
TEM05	Test Site		6/1/03		20000		5
TEM11			11/6/03		17000		150
TES03			3/27/04		14000		92
TEN03			3/27/04		26000		94
TEM03			3/27/04		32000		190
MPM05	Model	Riparian	6/1/03	Ferric Iron	13000		5
TPM05	Test Site		6/1/03		31000		5
TPM11			11/6/03		59000		29
TPN03	Test Site		3/27/04		4200		14
TPS03			3/27/04		17000		13
TPM03			3/27/04		23000		12
MRM05	Model	River	6/1/03	Ferric Iron	19000		5
TRM05	Test Site		6/1/03		55000		5
TRM11			11/6/03		66000		25
TRM03			3/27/04		100000		48
TRN03			3/27/04		120000		42
TRS03			3/27/04		170000		110
MEM05	Model	Ecotone	6/1/03	Ferrous Iron	BQL	U	6.1
TEM05	Test Site		6/1/03		BQL	U	9.2
TEM11			11/6/03		BQL	U	8.9

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (mg/kg)	Qualifiers	Detection Limit (mg/kg)
TEM03			3/27/04		14		9.9
TES03			3/27/04		100		9.0
TEN03			3/27/04		BQL	U	11
MPM05	Model	Riparian	6/1/03	Ferrous Iron	BQL	U	6.2
TPM05	Test Site		6/1/03		BQL	U	6.7
TPM11			11/6/03		12		7.5
TPN03			3/27/04		19		10
TPM03			3/27/04		100		7
TPS03			3/27/04		BQL	U	6
MRM05	Model	River	6/1/03	Ferrous Iron	BQL	U	6.8
TRM05	Test Site		6/1/03		BQL	U	15.0
TRM11			11/6/03		BQL	U	13
TRN03			3/27/04		BQL	U	14
TRM03			3/27/04		BQL	U	13
TRS03			3/27/04		BQL	U	14
TEM03 DUP	Test Site	Ecotone	3/27/04	Nitrate as N	BQL		0.9
MEM05	Model	Ecotone	6/1/03	Nitrate/Nitrite	BQL	U	2.2
TEM05	Test Site		6/1/03		BQL	U	3.5
TEM11			11/6/03		BQL	U	2.2
TEN03			3/27/04		BQL	U	0.87
TEM03			3/27/04		BQL	U	0.92
TES03			3/27/04		BQL	U	0.91
MPM05	Model	Riparian	6/1/03	Nitrate/Nitrite	BQL	U	2.3
TPM05	Test Site		6/1/03		BQL	U	2.6
TPM11			11/6/03		9.4		2.2
TPN03			3/27/04		BQL	U	0.65
TPM03			3/27/04		BQL	U	0.54
TPS03			3/27/04		BQL	U	0.59
MRM05	Model	River	6/1/03	Nitrate/Nitrite	BQL	U	2.5
TRM05	Test Site		6/1/03		8.6		5.9
TRM11			11/6/03		18		3.3
TRN03			3/27/04		BQL	U	0.99
TRM03			3/27/04		BQL	U	1.20
TRS03			3/27/04		BQL	U	1.00
MEM05	Model	Ecotone	6/1/03	Nitrite	BQL	U	0.9
TEM05	Test Site		6/1/03		BQL	U	1.4
TEN03			3/27/04		BQL	U	0.35
TEM03			3/27/04		BQL	U	0.37
TES03			3/27/04		BQL	U	0.37
MPM05	Model	Riparian	6/1/03	Nitrite	BQL	U	0.9
TPM05	Test Site		6/1/03		1.3		1.1
TPN03			3/27/04		BQL	U	0.26
TPM03			3/27/04		BQL	U	0.22
TPS03			3/27/2004		BQL	U	0.24
MRM05	Model	River	6/1/03	Nitrite	BQL	U	1.0
TRM05	Test Site		6/1/03		BQL	U	2.4
TRN03			3/27/04		BQL	U	0.40
TRM03			3/27/04		BQL	U	0.46

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (mg/kg)	Qualifiers	Detection Limit (mg/kg)
TRS03			3/27/04		BQL	U	0.42
MEM05	Model	Ecotone	6/1/03	Sulfate	270		61
TEM05	Test Site		6/1/03		1900		360
TEM11			11/6/03		2900		88
TEN03			3/27/04		1000		89
TEM03			3/27/04		680		18
TEM03 DUP			3/27/04		1800		18.5
TES03			3/27/04		950		37
MPM05	Model	Riparian	6/1/03	Sulfate	260		12
TPM05	Test Site		6/1/03		1100		67
TPM11			11/6/03		2000		75
TPN03			3/27/04		120		14
TPM03			3/27/04		110		11
TPS03			3/27/04		76		12
MRM05	Model	River	6/1/03	Sulfate	1000		67
TRM05	Test Site		6/1/03		660		30
TRM11			11/6/03		1100		26
TRN03			3/27/04		750		20
TRM03			3/27/04		450		22
TRS03			3/27/04		740		21
MEM05	Model	Ecotone	6/1/03	Total Organic Carbon	2300		140
TEM05	Test Site		6/1/03		46000		1500
TEM11			11/6/03		50000		6000
TEN03			3/27/04		49000		2800
TEM03 DUP			3/27/04		40000		92.7
TEM03			3/27/04		67000		4200
TES03			3/27/04		34000		2900
MPM05	Model	Riparian	6/1/03	Total Organic Carbon	1300		140
TPM05	Test Site		6/1/03		5900		220
TPN03	Test Site		3/27/04		19000		2000
TPM03	Test Site		3/27/04		7100		440
TPS03	Test Site		3/27/04		3200		930
MRM05	Model	River	6/1/03	Total Organic Carbon	4600		180
TRM05	Test Site		6/1/03		70000		2300
TRN03	Test Site		3/27/04		46000		4400
TRM03	Test Site		3/27/04		53000		2500
TRS03	Test Site		3/27/04		40000		2000
MEM05	Model	Ecotone	6/1/03	Total Kjeldahl Nitrogen	400		7.1
REM05	Recovering		6/1/03		570		8.7
TEM05	Test Site		6/1/03		830		27
TEM11			11/6/03		1000		5.0
TEN03			3/27/04		1200		28.0
TEM03			3/27/04		1400		32
TES03			3/27/04		1300		25
MPM05	Model	Riparian	6/1/03	Total Kjeldahl	190		3.6

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (mg/kg)	Qualifiers	Detection Limit (mg/kg)
				Nitrogen			
TPM05	Test Site		6/1/03		390		7.8
TPN03			3/27/04		750		21.0
TPM03			3/27/04		47		3.7
TPS03			3/27/04		230		3.3
MRM05	Model	River	6/1/03	Total Kjeldahl Nitrogen	600		19.0
TRM05	Test Site		6/1/03		550		9.4
TRN03			3/27/04		1800		27.0
TRM03			3/27/04		1600		39.0
TRS03			3/27/04		1900		37.0
				Total Phosphorus (as P)			
MEM05	Model	Ecotone	6/1/03	Total Phosphorus (as P)	820		57
TEM05	Test Site		6/1/03		1100		84
TEM11			11/6/03		650		33
TEN03			3/27/04		800		1.9
TEM03			3/27/04		830		2
TES03			3/27/04		320		1.8
				Total Phosphorus (as P)			
MPM05	Model	Riparian	6/1/03	Total Phosphorus (as P)	930		55
TPM05	Test Site		6/1/03		1200		67
TPM11			11/6/03		520		28
TPN03			3/27/04		170		1.4
TPM03			3/27/04		380		1.2
TPS03			3/27/04		190		1.2
				Total Phosphorus (as P)			
MRM05	Model	River	6/1/03	Total Phosphorus (as P)	770		54
TRM05	Test Site		6/1/03		3200		150
TRM11			11/6/03		780		51
TRN03			3/27/04		810		2
TRM03			3/27/04		1200		2
TRS03			3/27/04		910		2

Table 7-4. Oil & Grease and Total Petroleum Hydrocarbons (TPH) Summary

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result	Units	Qualifiers	Detection Limit
MEM05	Model	Ecotone	6/1/03	Oil & Grease	BQL	mg/kg	U	300
TEM05	Test Site		6/1/03		2100			450
TEM11			11/6/03		1.60			0.4
TEN03			3/27/04		700			460
TEM03			3/27/04		1200			500
TES03			3/27/04		BQL		U	440
MPM05	Model	Riparian	6/1/03	Oil & Grease	BQL	mg/kg	U	310
TPM05	Test Site		6/1/03		360			340
MRM05	Model	River	6/1/03	Oil & Grease	BQL	mg/kg	U	330

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result	Units	Qualifiers	Detection Limit
TRM05	Test Site		6/1/03		5600			770
WMRM05	Model	River Water	6/1/03	Oil & Grease	5.10	mg/L		5.0
WTRM05	Test Site		6/1/03		6.50			5.0
WTRM11			11/6/03		5.7			5.0
MEM05	Model	Ecotone	6/1/03	Total Petroleum Hydrocarbons	93	mg/kg		30
TEM05	Test Site		6/1/03		20000			230
TEM11			11/6/03		330			44
TEN03			3/27/04		320			47
TEM03			3/27/04		3200			490
TES03			3/27/04		260			46
MPM05	Model	Riparian	6/1/03	Total Petroleum Hydrocarbons	BQL	mg/kg	U	30
TPM05	Test Site		6/1/03		44			34
TPN03			3/27/04		65			36
TPM03			3/27/04		38			32
TPS03			3/27/04		36			31
MRM05	Model	River	6/1/03	Total Petroleum Hydrocarbons	44	mg/kg		33
TRM05	Test Site		6/1/03		590			77
TRN03			3/27/04		1600			260
TRM03			3/27/04		860			60
TRS03			3/27/04		4600			280

Table 7-5. Polychlorinated Biphenyl (PCB) Summary

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TOTAL	Test Site	River	6/1/03	Aroclor	180		
TOTAL	Test Site	Ecotone	6/1/03	Aroclor	150		
TOTAL	Test Site	Riparian	6/1/03	Aroclor	BQL		
TOTAL	Test Site	River	11/6/03	Aroclor			
TOTAL	Test Site	Ecotone	11/6/03	Aroclor	34		
TOTAL	Test Site	Riparian	11/6/03	Aroclor			
TOTAL	Test Site	River	3/27/04	Aroclor	3443		
TOTAL	Test Site	Ecotone	3/27/04	Aroclor	210		
TOTAL	Test Site	Riparian	3/27/04	Aroclor	14		
MEM05	Model	Ecotone	6/1/03	Aroclor 1232	BQL	U	41
TEM05	Test Site		6/1/03		BQL	U	62
TEM11			11/6/03		BQL	U	60
TEM03 DUP			3/27/04		BQL		61
TEN03			3/27/04		BQL	U	63
TEM03			3/27/04		BQL	U	67
TES03			3/27/04		BQL	U	62

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
MPM05	Model	Riparian	6/1/03	Aroclor 1232	BQL	U	41
TPM05	Test Site		6/1/03		BQL	U	45
TPN03			3/27/04		BQL	U	49
TPM03			3/27/04		BQL	U	43
TPS03			3/27/04		BQL	U	42
MRM05	Model	River	6/1/03	Aroclor 1232	BQL	U	46
TRM05	Test Site		6/1/03		BQL	U	100
TRN03 DL			3/27/04		2200		350
TRM03 DL			3/27/04		1100		160
TRS03 DL			3/27/04		3700		370
MEM05	Model	Ecotone	6/1/03	Aroclor 1254	BQL	U	41
TEM05	Test Site		6/1/03		BQL	U	62
TEM11			11/6/03		BQL	U	60
TEM03 DUP			3/27/04		BQL		61
TEN03			3/27/04		BQL	U	63
TEM03			3/27/04		BQL	U	67
TES03			3/27/04		BQL	U	62
MPM05	Model	Riparian	6/1/03	Aroclor 1254	BQL	U	41
TPM05	Test Site		6/1/03		BQL	U	45
TPN03			3/27/04		BQL	U	49
TPM03			3/27/04		BQL	U	43
TPS03			3/27/2004		BQL	U	42
MRM05	Model	River	6/1/03	Aroclor 1254	BQL	U	46
TRM05	Test Site	River	6/1/03		BQL	U	100
TRN03 DL			3/27/04		870		350
TRM03 DL			3/27/04		550		160
TRS03 DL			3/27/04		1900		370
MEM05	Model	Ecotone	6/1/03	Aroclor 1260	BQL	U	41
TEM05	Test Site		6/1/03		150		62
TEM11			11/6/03		34	J	60
TEN03			3/27/04		390	P	63
TEM03 DUP			3/27/04		220		61
TEM03			3/27/04		210		67
TES03			3/27/04		21	J	62
MPM05	Model	Riparian	6/1/03	Aroclor 1260	BQL	U	41
TPM05	Test Site		6/1/03		BQL	U	45
TPN03			3/27/04		17	P	49
TPM03			3/27/04		10	P	43
TPS03			3/27/04		BQL	U	42
MRM05	Model	River	6/1/03	Aroclor 1260	BQL	U	46
TRM05	Test Site		6/1/03		180		100
TRN03 DL			3/27/04		BQL	U	350
TRM03 DL			3/27/04		BQL	U	160
TRS03 DL			3/27/04		BQL	U	370

Table 7-6. Pesticides Summary

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TOTAL	Test Site	River	6/1/03	Pesticides	51.6		
		Ecotone	6/1/03	Pesticides	68.6		
		Riparian	6/1/03	Pesticides	50		
TOTAL	Test Site	River	3/27/03	Pesticides	99		
		Ecotone	3/27/03	Pesticides	39		
		Riparian	3/27/03	Pesticides	1		
MEM05	Model	Ecotone	6/1/03	4,4-DDD	BQL	U	2.1
TEM05	Test Site		6/1/03		1.3	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		7.60		3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	4,4-DDD	BQL	U	2.1
TPM05	Test Site		6/1/03		9	P	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	4,4-DDD	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37
MEM05	Model	Ecotone	6/1/03	4,4'-DDE	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		1.80	J, PG	3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	4,4'-DDE	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	4,4'-DDE	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		9	J	35
TRM03 DL			3/27/04		17	J	41
TRS03 DL			3/27/04		16	J	37
MEM05	Model	Ecotone	6/1/03	4,4'-DDT	BQL	U	2.1
TEM05	Test Site		6/1/03		3.6	U	3.1
TEN03			3/27/04		37		3.1
TEM03 DUP			3/27/04		BQL		3.2
TEM03			3/27/04		14		3.3
TES03			3/27/04		5	P	3.1

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
MPM05	Model	Riparian	6/1/03	4,4'-DDT	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	4,4'-DDT	BQL	U	2.3
TRM05	Test Site		6/1/03		3.2	U	5.2
TRN03 DL			3/27/04		36		35
TRM03 DL			3/27/04		87		41
TRS03 DL			3/27/04		76		37
MEM05	Model	Ecotone	6/1/03	alpha-BHC	BQL	U	2.1
TEM05	Test Site		6/1/03		0.48	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		BQL		3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	alpha-BHC	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	alpha-BHC	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37
MEM05	Model	Ecotone	6/1/03	alpha-chlordane	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		0.77	J, PG	3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	alpha-chlordane	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	alpha-chlordane	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		6.90	J	37
MEM05	Model	Ecotone	6/1/03	beta-BHC	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEM03 DUP			3/27/04		2.6	J, PG	3.2
TEN03			3/27/04		BQL	U	3.1
TEM03			3/27/04		BQL	U	3.3

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	beta-BHC	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	beta-BHC	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37
MEM05	Model	Ecotone	6/1/03	dieldrin	BQL	U	2.1
TEM05	Test Site		6/1/03		2.1	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		BQL		3.2
TEM03			3/27/04		5.2	P	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	dieldrin	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	dieldrin	BQL	U	2.3
TRM05	Test Site		6/1/03		2.1	U	5.2
TRN03 DL			3/27/04		12	J	35
TRM03 DL			3/27/04		24	J	41
TRS03 DL			3/27/04		21	J	37
MEM05	Model	Ecotone	6/1/03	endrin aldehyde	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03			3/27/04		BQL	U	3.3
TEM03 DUP			3/27/04		BQL		3.2
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	endrin aldehyde	BQL	U	2.1
TPM05	Test Site		6/1/03		11	P	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	endrin aldehyde	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37
MEM05	Model	Ecotone	6/1/03	endosulfan sulfate	BQL	U	2.1
TEM05	Test Site		6/1/03		6.1	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		BQL		3.2

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	endosulfan sulfate	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	endosulfan sulfate	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37
MEM05	Model	Ecotone	6/1/03	endrin	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		0.90	J, PG	3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	endrin	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		1	J	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	endrin	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		26	J	35
TRM03 DL			3/27/04		53	P	41
TRS03 DL			3/27/04		49	P	37
MEM05	Model	Ecotone	6/1/03	gamma-chlordane	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEN03			3/27/04		BQL	U	3.1
TEM03 DUP			3/27/04		1.10	J, PG	3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	gamma-chlordane	BQL	U	2.1
TPM05	Test Site		6/1/03		BQL	U	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	gamma-chlordane	BQL	U	2.3
TRM05	Test Site		6/1/03		3.7	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37
MEM05	Model	Ecotone	6/1/03	methoxychlor	BQL	U	2.1
TEM05	Test Site		6/1/03		BQL	U	3.1
TEN03			3/27/04		BQL	U	3.1

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TEM03 DUP			3/27/04		BQL		3.2
TEM03			3/27/04		BQL	U	3.3
TES03			3/27/04		BQL	U	3.1
MPM05	Model	Riparian	6/1/03	methoxychlor	BQL	U	2.1
TPM05	Test Site		6/1/03		30	P	2.3
TPN03			3/27/04		BQL	U	2.5
TPM03			3/27/04		BQL	U	2.2
TPS03			3/27/04		BQL	U	21
MRM05	Model	River	6/1/03	methoxychlor	BQL	U	2.3
TRM05	Test Site		6/1/03		BQL	U	5.2
TRN03 DL			3/27/04		BQL	U	35
TRM03 DL			3/27/04		BQL	U	41
TRS03 DL			3/27/04		BQL	U	37

Table 7-7. Leachable Metals Summary

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/L)	Qualifiers	Detection Limit (ug/L)
MEM05	Model	Ecotone	6/1/03	arsenic	BQL	U	200
TEM05	Test Site		6/1/03		BQL	U	200
TEN03			3/27/04		BQL	U	200
TEM03			3/27/04		BQL	U	200
TEM03 DUP			3/27/04		170		1000
TES03			3/27/04		BQL	U	200
MPM05	Model	Riparian	6/1/03	arsenic	BQL	U	200
TPM05	Test Site		6/1/03		BQL	U	200
TPN03			3/27/04		BQL	U	200
TPM03			3/27/04		BQL	U	200
TPS03			3/27/04		BQL	U	200
MRM05	Model	River	6/1/03	arsenic	BQL	U	200
TRM05	Test Site		6/1/03		BQL	U	200
TRN03			3/27/04		BQL	U	200
TRM03			3/27/04		BQL	U	200
TRS03			3/27/04		BQL	U	200
MEM05	Model	Ecotone	6/1/03	barium	BQL	U	1000
TEM05	Test Site		6/1/03		1050		1000
TEN03			3/27/04		1240		1000
TEM03			3/27/04		1280		1000
TEM03 DUP			3/27/04		840		10000
TES03			3/27/04		BQL	U	1000
MPM05	Model	Riparian	6/1/03	barium	BQL	U	1000
TPM05	Test Site		6/1/03		BQL	U	1000
TPN03			3/27/04		BQL	U	1000
TPM03			3/27/04		BQL	U	1000
TPS03			3/27/04		BQL	U	1000
MRM05	Model	River	6/1/03	barium	BQL	U	1000

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/L)	Qualifiers	Detection Limit (ug/L)
TRM05	Test Site		6/1/03		BQL	U	1000
TRN03			3/27/04		1080		1000
TRM03			3/27/04		BQL		1000
TRS03			3/27/04		1150		1000
MEM05	Model	Ecotone	6/1/03	chromium	BQL	U	50
TEM05	Test Site		6/1/03		361		50
TEN03			3/27/04		BQL		50
TEM03			3/27/04		BQL		50
TEM03 DUP			3/27/04		16		500
TES03			3/27/04		BQL		50
MPM05	Model	Riparian	6/1/03	chromium	BQL	U	50
TPM05	Test Site		6/1/03		BQL	U	50
TPN03			3/27/04		BQL		50
TPM03			3/27/04		BQL		50
TPS03			3/27/04		BQL		50
MRM05	Model	River	6/1/03	chromium	BQL	U	50
TRM05	Test Site		6/1/03		BQL	U	50
TRN03			3/27/04		BQL		50
TRM03			3/27/04		BQL		50
TRS03			3/27/04		BQL		50
MEM05	Model	Ecotone	6/1/03	iron	15200		1500
TEM05	Test Site		6/1/03		1210000		1500
TEN03			3/27/04		346000		1500
TEM03			3/27/04		381000		1500
TES03			3/27/04		479000		1500
TEM03 DUP			3/27/04		431000		200
MPM05	Model	Riparian	6/1/03	iron	BQL	U	1500
TPM05	Test Site		6/1/03		BQL	U	1500
TPN03			3/27/04		BQL		1500
TPM03			3/27/04		BQL		1500
TPS03			3/27/04		BQL		1500
MRM05	Model	River	6/1/03	iron	BQL	U	1500
TRM05	Test Site		6/1/03		BQL	U	1500
TRN03			3/27/04		140000		1500
TRM03			3/27/04		173000		1500
TRS03			3/27/04		389000		1500
MEM05	Model	Ecotone	6/1/03	manganese	1830		50
TEM05	Test Site		6/1/03		15500		50
TEM11			11/6/03		7740		50
TEN03			3/27/04		16000		50
TEM03			3/27/04		4540		50
TES03			3/27/04		4420		50
TEM03 DUP			3/27/04		6400		30
MPM05	Model	Riparian	6/1/03	manganese	307		50
TPM05	Test Site		6/1/03		3540		50
TPN03			3/27/04		2650		50
TPM03			3/27/04		1980		50

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/L)	Qualifiers	Detection Limit (ug/L)
TPS03			3/27/04		2310		50
MRM05	Model	River	6/1/03	manganese	5130		50
TRM05	Test Site		6/1/03		20600		50
TRN03			3/27/04		8710		50
TRM03			3/27/04		9720		50
TRS03			3/27/04		21500		50
MEM05	Model	Ecotone	6/1/03	nickel	BQL	U	100
TEM05	Test Site		6/1/03		608		100
TEN03			3/27/04		423		100
TEM03			3/27/04		178		100
TEM03 DUP			3/27/04		200		40
TES03			3/27/04		BQL	U	100
MPM05	Model	Riparian	6/1/03	nickel	BQL	U	100
TPM05	Test Site		6/1/03		BQL	U	100
TPN03			3/27/04		BQL	U	100
TPM03			3/27/04		BQL	U	100
TPS03			3/27/04		BQL	U	100
MRM05	Model	River	6/1/03	nickel	BQL	U	100
TRM05	Test Site		6/1/03		148		100
TRN03			3/27/04		295		100
TRM03			3/27/04		229		100
TRS03			3/27/04		851		100
MEM05	Model	Ecotone	6/1/03	selenium	BQL	U	200
TEM05	Test Site		6/1/03		BQL	U	200
TEN03			3/27/04		BQL	U	200
TEM03			3/27/04		BQL	U	200
TEM03 DUP			3/27/04		110		500
TES03			3/27/04		BQL	U	200
MPM05	Model	Riparian	6/1/03	selenium	BQL	U	200
TPM05	Test Site		6/1/03		BQL	U	200
TPN03			3/27/04		BQL	U	200
TPM03			3/27/04		BQL	U	200
TPS03			3/27/04		BQL	U	200
MRM05	Model	River	6/1/03	selenium	BQL	U	200
TRM05	Test Site		6/1/03		BQL	U	200
TRN03			3/27/04		BQL	U	200
TRM03			3/27/04		BQL	U	200
TRS03			3/27/04		BQL	U	200
MEM05	Model	Ecotone	6/1/03	zinc	217		200
TEM05	Test Site		6/1/03		1690		200
TEM11			11/6/03		3790		200
TEN03			3/27/04		1640		200
TEM03			3/27/04		384		200
TEM03 DUP			3/27/04		360		40
TES03			3/27/04		323		200
MPM05	Model	Riparian	6/1/03	zinc	1540		200
TPM05	Test Site		6/1/03		BQL	U	200

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/L)	Qualifiers	Detection Limit (ug/L)
TPN03			3/27/04		8090		200
TPM03			3/27/04		471		200
TPS03			3/27/04		BQL	U	200
MRM05	Model	River	6/1/03	zinc	BQL	U	200
TRM05	Test Site		6/1/03		2480		200
TRN03			3/27/04		1060		200
TRM03			3/27/04		354		200
TRS03			3/27/04		1500		200

Table 7-8. Polycyclic Aromatic Hydrocarbons (PAHs) Summary

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TOTAL	Test Site	River	6/1/03	PAHs	18190		
		Ecotone	6/1/03	PAHs	28670		
		Riparian	6/1/03	PAHs	108298		
TOTAL	Test Site	River	11/6/03	PAHs			
		Ecotone	11/6/03	PAHs	7352		
		Riparian	11/6/03	PAHs			
TOTAL	Test Site	River	3/27/04	PAHs	11555		
		Ecotone	3/27/04	PAHs	22519		
		Riparian	3/27/04	PAHs	8026		
MEM05	Model	Ecotone	6/1/03	acenaphthene	BQL	U	410
TEM05	Test Site		6/1/03		200	J	620
TEM11			11/6/03		BQL		600
TEM11 RE			11/6/03		BQL	U	600
TEN03			3/27/04		BQL	U	630
TEM03 DUP			3/27/04		180	J	2400
TEM03			3/27/04		220	J	670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		100	J	620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	acenaphthene	BQL		410
TPM05	Test Site		6/1/03		370	J	450
TPM05DL			6/1/03		BQL	U	4500
TPN03			3/27/04		BQL	U	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	acenaphthene	BQL	U	460
TRM05	Test Site		6/1/03		BQL		1000
TRN03			3/27/04		BQL	U	700
TRM03			3/27/04		140	J	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		140	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	acenaphthylene	BQL	U	410

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TEM05	Test Site		6/1/03		690		620
TEM11			11/6/03		110	U	600
TEM11 RE			11/6/03		52	J	600
TEN03			3/27/04		260	J	630
TEM03			3/27/04		640	J	670
TEM03DL			3/27/04		590	U	6700
TES03			3/27/04		200	J	620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	acenaphthylene	BQL		410
TPM05	Test Site		6/1/03		290	J	450
TPM05DL			6/1/03		BQL	U	4500
TPN03			3/27/04		85	J	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	acenaphthylene	BQL	U	460
TRM05	Test Site		6/1/03		150	U	1000
TRN03			3/27/04		160	J	700
TRM03			3/27/04		220	J	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		210	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	anthracene	BQL	U	410
TEM05	Test Site		6/1/03		690		620
TEM11			11/6/03		270	J	600
TEM11 RE			11/6/03		96	J	600
TEN03			3/27/04		350	J	630
TEM03 DUP			3/27/04		710	J	2400
TEM03			3/27/04		870		670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		360		620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	anthracene	BQL		410
TPM05	Test Site		6/1/03		3300		450
TPM05DL			6/1/03		3400	J	4500
TPN03			3/27/04		160	J	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	anthracene	BQL	U	460
TRM05	Test Site		6/1/03		230	J	1000
TRN03			3/27/04		210	J	700
TRM03			3/27/04		280	J	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		160	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	benzo(a) anthracene	BQL	U	410
TEM05	Test Site		6/1/03		3800		620
TEM11			11/6/03		1000	J	600
TEM11 RE			11/6/03		420	J	600

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TEN03			3/27/04		1900		630
TEM03 DUP			3/27/04		2500		2400
TEM03			3/27/04		3700		670
TEM03DL			3/27/04		4100	J	6700
TES03			3/27/04		1600		620
TES03DL			3/27/04		1600	J	6200
MPM05	Model	Riparian	6/1/03	benzo(a) anthracene	BQL		410
TPM05DL	Test Site		6/1/03		6700		4500
TPN03			3/27/04		660		490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	benzo(a) anthracene	BQL	U	460
TRM05	Test Site		6/1/03		1200	J	1000
TRN03			3/27/04		1300		820
TRM03			3/27/04		1600		820
TRM03DL			3/27/04		1700	J	8200
TRS03			3/27/04		790		750
TRS03DL			3/27/04		1000	J	7500
MEM05	Model	Ecotone	6/1/03	benzo(a)pyrene	BQL	U	410
TEM05	Test Site		6/1/03		3500		620
TEM11			11/6/03		820		600
TEN03			3/27/04		1400		630
TEM03			3/27/04		3000		670
TEM03DL			3/27/04		2900	J	6700
TES03			3/27/04		1100		620
TES03DL			3/27/04		1000	J	6200
MPM05	Model	Riparian	6/1/03	benzo(a)pyrene	BQL		410
TPM05	Test Site		6/1/03		4600		450
TPM05DL			6/1/03		4800		4500
TPN03			3/27/04		480	J	490
TPM03			3/27/04		39	J	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	benzo(a)pyrene	BQL	U	460
TRM05	Test Site		6/1/03		1300		1000
TRN03			3/27/04		1100		700
TRM03			3/27/04		1400		820
TRM03DL			3/27/04		1400		8200
TRS03			3/27/04		810		750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	benzo(b) fluoranthene	BQL	U	410
TEM05	Test Site		6/1/03		3700		620
TEM11			11/6/03		1100		600
TEM11 RE			11/6/03		430	J	600
TEN03			3/27/04		1700		630
TEM03 DUP			3/27/04		2800		2400
TEM03			3/27/04		3400		670
TEM03DL			3/27/04		4500	J	6700
TES03			3/27/04		1500		620

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	benzo(b) fluoranthene	BQL	U	410
TPM05	Test Site		6/1/03		5600		450
TPM05DL			6/1/03		6000		4500
TPN03			3/27/04		710		490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	422
MRM05	Model	River	6/1/03	benzo(b) fluoranthene	BQL	U	460
TRM05	Test Site		6/1/03		1800		1000
TRN03			3/27/04		1800		700
TRM03			3/27/04		1800		820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		1100		750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	benzo(ghi) perylene	BQL	U	410
TEM05	Test Site		6/1/03		1700		620
TEM11			11/6/03		490	J	600
TEM11 RE			11/6/03		170	J	600
TEN03			3/27/04		1100	J	630
TEM03 DUP			3/27/04		1600	J	2400
TEM03			3/27/04		1800		670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		820		620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	benzo(ghi) perylene	BQL	U	410
TPM05	Test Site		6/1/03		2000		450
TPM05DL			6/1/03		1900	J	4500
TPN03			3/27/04		280	J	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	423
MRM05	Model	River	6/1/03	benzo(ghi) perylene	BQL	U	460
TRM05	Test Site		6/1/03		1000	J	1000
TRN03			3/27/04		1000		700
TRM03			3/27/04		1300		820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		500	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	benzo(k) fluoranthene	BQL	U	410
TEM05	Test Site		6/1/03		1400		620
TEM11			11/6/03		340	J	600
TEM11 RE			11/6/03		150	J	600
TEN03			3/27/04		600	J	630
TEM03 DUP			3/27/04		980	J	2400
TEM03			3/27/04		1100		670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		440	J	620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	benzo(k) fluoranthene	BQL		410

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TPM05	Test Site		6/1/03		1900		450
TPM05DL			6/1/03		2000	J	4500
TPN03			3/27/04		200	J	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	424
MRM05	Model	River	6/1/03	benzo(k) fluoranthene	BQL	U	460
TRM05	Test Site		6/1/03		690	J	1000
TRN03			3/27/04		340	J	700
TRM03			3/27/04		670	J	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		370	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	chrysene	BQL	U	410
TEM05	Test Site		6/1/03		2600		620
TEM11			11/6/03		750		600
TEM11 RE			11/6/03		310	J	600
TEN03			3/27/04		1200		630
TEM03 DUP			3/27/04		2200	J	2400
TEM03			3/27/04		2800		670
TEM03DL			3/27/04		2600	J	6700
TES03			3/27/04		1200		620
TES03DL			3/27/04		1000	J	6200
MPM05	Model	Riparian	6/1/03	chrysene	BQL	U	410
TPM05	Test Site		6/1/03		5200		450
TPM05DL			6/1/03		5100		4500
TPN03			3/27/04		510		490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	425
MRM05	Model	River	6/1/03	chrysene	BQL	U	460
TRM05	Test Site		6/1/03		1300		1000
TRN03			3/27/04		1200		700
TRM03			3/27/04		1500		820
TRM03DL			3/27/04		1600	J	8200
TRS03			3/27/04		1000		750
TRS03DL			3/27/04		970	J	7500
MEM05	Model	Ecotone	6/1/03	dibenz(a,h) anthracene	BQL	U	410
TEM05	Test Site		6/1/03		BQL	U	620
TEM11			11/6/03		BQL	U	600
TEM11 RE			11/6/03		BQL	U	600
TEN03			3/27/04		BQL	U	630
TEM03			3/27/04		590	J	670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		260	J	620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	dibenz(a,h) anthracene	BQL		410
TPM05	Test Site		6/1/03		BQL	U	450
TPM05DL			6/1/03		BQL	U	4500
TPN03			3/27/04		BQL	U	490

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	426
MRM05	Model	River	6/1/03	dibenz(a,h) anthracene	BQL	U	460
TRM05	Test Site		6/1/03		BQL	U	1000
TRN03			3/27/04		310	J	700
TRM03			3/27/04		BQL	U	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		BQL	U	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	fluoranthene	BQL	U	410
TEM05	Test Site		6/1/03		2800		620
TEM11			11/6/03		950		600.0
TEM11 RE			11/6/03		470	J	600.0
TEN03			3/27/04		1600		630
TEM03 DUP			3/27/04		2600	J	2400
TEM03			3/27/04		3400		670
TEM03DL			3/27/04		4700	J	6700
TES03			3/27/04		1800		620
TES03DL			3/27/04		1400	J	6200
MPM05	Model	Riparian	6/1/03	fluoranthene	BQL	U	410
TPM05	Test Site		6/1/03		99800	E	450
TPM05DL			6/1/03		15000		4500
TPN03			3/27/04		1100		490
TPM03			3/27/04		85	J	430
TPS03			3/27/04		BQL	U	427
MRM05	Model	River	6/1/03	fluoranthene	BQL	U	460
TRM05	Test Site		6/1/03		2500		1000
TRN03			3/27/04		1900		700
TRM03			3/27/04		2100		820
TRM03DL			3/27/04		3300	J	8200
TRS03			3/27/04		1400		750
TRS03DL			3/27/04		2100	J	7500
MEM05	Model	Ecotone	6/1/03	fluorene	BQL	U	410
TEM05	Test Site		6/1/03		500	J	620
TEM11			11/6/03		BQL	U	600
TEM11 RE			11/6/03		BQL	U	600
TEN03			3/27/04		120	U	630
TEM03			3/27/04		290	J	670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		1400	J	620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	fluorene	BQL	U	410
TPM05	Test Site		6/1/03		980		450
TPM05DL			6/1/03		1000	J	4500
TPN03			3/27/04		BQL	U	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	fluorene	BQL	U	460

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TRM05	Test Site		6/1/03		150	J	1000
TRN03			3/27/04		88	J	700
TRM03			3/27/04		150	J	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		BQL	U	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	indeno(1,2,3-cd) pyrene	BQL	U	410
TEM05	Test Site		6/1/03		1800		620
TEM11			11/6/03		430	J	600
TEM11 RE			11/6/03		160	J	600
TEM03 DUP			3/27/04		1300	J	2400
TEN03			3/27/04		940		630
TEM03			3/27/04		1700		670
TEM03DL			3/27/04		1300	J	6700
TES03			3/27/04		740		620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	indeno(1,2,3-cd) pyrene	BQL		410
TPM05	Test Site		6/1/03		2000		450
TPM05DL			6/1/03		2000	J	4500
TPN03			3/27/04		260	J	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	indeno(1,2,3-cd) pyrene	BQL	U	460
TRM05	Test Site		6/1/03		890	J	1000
TRN03			3/27/04		810		700
TRM03			3/27/04		1100		820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		500	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	naphthalene	BQL	U	410
TEM05	Test Site		6/1/03		270	J	620
TEM11			11/6/03		70	J	600
TEM11 RE			11/6/03		BQL	U	600
TEN03			3/27/04		140	J	630
TEM03 DUP			3/27/04		380	J	2400
TEM03			3/27/04		240	J	670
TEM03DL			3/27/04		BQL	U	6700
TES03			3/27/04		86	J	620
TES03DL			3/27/04		BQL	U	6200
MPM05	Model	Riparian	6/1/03	naphthalene	BQL		410
TPM05	Test Site		6/1/03		98		450
TPM05DL			6/1/03		BQL	U	4500
TPN03			3/27/04		BQL	U	490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	naphthalene	BQL	U	460
TRM05	Test Site		6/1/03		140	J	1000
TRN03			3/27/04		100	J	700

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TRM03			3/27/04		130	J	820
TRM03DL			3/27/04		BQL	U	8200
TRS03			3/27/04		130	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	phenanthrene	BQL	U	410
TEM05	Test Site		6/1/03		1400		620
TEM11			11/6/03		560	J	600
TEM11 RE			11/6/03		230	J	600
TEN03			3/27/04		1000		630
TEM03 DUP			3/27/04		1300	J	2400
TEM03			3/27/04		1900		670
TEM03DL			3/27/04		1800	J	6700
TES03			3/27/04		910		620
TES03DL			3/27/04		770	J	6200
MPM05	Model	Riparian	6/1/03	phenanthrene	BQL	U	410
TPM05	Test Site		6/1/03		8300	E	450
TPM05DL			6/1/03		9200		4500
TPN03			3/27/04		510		490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	phenanthrene	BQL	U	460
TRM05	Test Site		6/1/03		1000	J	1000
TRN03			3/27/04		730	J	700
TRM03			3/27/04		1200		820
TRM03DL			3/27/04		1400	J	8200
TRS03			3/27/04		740	J	750
TRS03DL			3/27/04		BQL	U	7500
MEM05	Model	Ecotone	6/1/03	pyrene	BQL	U	410
TEM05	Test Site		6/1/03		5600		620
TEM11			11/6/03		1500		600.0
TEM11 RE			11/6/03		520	J	600.0
TEN03			3/27/04		2700		630
TEM03 DUP			3/27/04		3900		2400
TEM03			3/27/04		5600		670
TEM03DL			3/27/04		5600	J	6700
TES03			3/27/04		3100		620
TES03DL			3/27/04		2600	J	6200
MPM05	Model	Riparian	6/1/03	pyrene	BQL	U	410
TPM05	Test Site		6/1/03		8300	E	450
TPM05DL			6/1/03		9300		4500
TPN03			3/27/04		1000		490
TPM03			3/27/04		BQL	U	430
TPS03			3/27/04		BQL	U	420
MRM05	Model	River	6/1/03	pyrene	BQL	U	460
TRM05	Test Site		6/1/03		2100		1000
TRN03			3/27/04		2000		700
TRM03			3/27/04		2400		820
TRM03DL			3/27/04		2600	J	8200

Sample No.	River Location	Zone Location	Date Collected	Analyte	Result (ug/kg)	Qualifiers	Detection Limit (ug/kg)
TRS03			3/27/04		1600		750
TRS03DL			3/27/04		1900	J	7500

7.2 BIOLOGICAL ANALYSIS

Samples collected during the initial sampling event (May and June, 2003) were sent to Lambda Bioremediation Systems, Inc. (Lambda) laboratory to be evaluated biologically. The purpose of this evaluation was to: 1) characterize the different microbial communities that were active in the river, ecotone, and riparian zones, 2) identify what microbes were needed to remediate the mixture of contaminants found in the Test Site, 3) identify the type and viability of the indigenous microbes present in the Model Reach, Recovering Area, and Test Site that could be used to remediate the contaminants, and 4) evaluate the health and density of existing microbial communities. Two analyses were performed. A BioScan™ and Microecological Profile™ were performed. Both of these procedures have been developed by Lambda over the last two decades. Both use a proprietary database listing the bacteria, protozoa, fungi, and algae and their functions. These functions are a critical part of the success of the treatment, in that the microbes have to work within the balanced ecosystem that already exists at the site while supporting each other to accomplish a complete destruction or treatment of the contaminant mixture. In other words, many of the microbes needed are active ingredients, actually accomplishing the transformation or destruction of the original contaminants. A significant portion of the microbes perform secondary destruction or transformation of the daughter or byproducts that are produced during the treatment process. A third set of microbes perform a supporting role, either by producing needed enzymes, balancing the pH, or reducing or producing ancillary products (such as nitrate and sulfate). The complete treatment community should consist of microbes that can operate in both an oxygen-rich (aerobic) or oxygen-depleted (anaerobic) environment, depending both on natural conditions and those that are created during the treatment duration.

7.2.1 BioScan™

The purpose of the BioScan™ is to identify the key microbes that are needed to perform the treatment and to see if they exist in samples of site soils. Lambda's proprietary database is searched to identify 30 to 40 microbes that are essential to treat the mixture of contaminants at the site. Then, individual test tubes are prepared, each containing a specifically-designed growth media that is unique to a single microbe. Samples of soils from the Model Reach, Recovering Area, and Test Site are used to seed each test tube. The tubes are then incubated and later read. The relative meaning of the numbers shown in Table 7-10 and 7-11 are presented in Table 7-9 below. The results of the BioScan™ readings are presented in Table 7-10. This table lists each microbe that was grown, along with its function or destruction target. The growth medium for each microbe is also listed. The results are shown as numbers, ranging from 1- to 3+. These numbers indicate the relative viability, density and health of each bacterium, protozoan, fungus, and algae.

7-9. DIFCO Industrial Microbial Scale

DIFCO Scale	Colonies Present	Microbial Count per Milliliter
0	No organisms found	None
1-	1 to 2 colonies	Approximately 10^2
1	3 to 6 colonies	Approximately 10^3
1+	7 to 9 colonies	$>10^3$ but $<10^4$
2-	10 to 20 colonies	Approximately 10^4
2	20 to 60 colonies	$>10^4$ but $<10^5$
2+	60 to 100 colonies	Approximately 10^5
3-	100 to 250 colonies	$>10^5$ but $<10^6$
3	300 to 500 colonies	Approximately 10^6
3+	> 500 colonies	$>10^6$ This is a 5:1 concentration at maximum carrying capacity

Source: DIFCO Manual, 10th edition, A.L. Lane, DIFCO Laboratories, Detroit MI, 1984.

7.2.2 MicroEcological Profile™

Once the results of the BioScan are known, a more comprehensive evaluation of the necessary microbial communities can be conducted, using the MicroEcological Profile™ (MEP). This is another proprietary Lambda process, much like the BioScan™. It is used to develop a comprehensive list of microbes that are needed in every step of the process used to treat the mixture of contaminants. Extensive research is performed to investigate newly-identified microbes that were recently found to have needed functions. Processes are broken down into logical steps to ensure that each function and byproduct is adequately addressed. Then, the comprehensive list of microbes is used to grow another set of test tubes to be read for density, viability, and health. Figure 7-1 shows a Lambda laboratory staff member preparing the growth media in test tubes. Figure 7-2 shows the vast array of growth media used to implement the process. Table 7-11 presents the results of the MEP™. This information is then used in several ways. First, it is used to identify the individual microbes that will be included in the design of the consortium. Second, it is used to determine the health of individual microbes in site soils. If a microbe that is needed for the consortium is not healthy as it occurs in the natural soils of the site, it will be mated with a pure strain “type culture” counterpart, purchased from American Type Culture Collection (ATCC). All purchased microbes are BioSafety Level I². This “hybridized” microbe is the same as the naturally-occurring one, but is healthier and better able to function under the stressful conditions imposed by site contamination.

² The classification is based on assessment of the potential risk using US Public Health Service guidelines, with assistance provided by the American Type Culture Council (ATCC) scientific advisory committees. Those items in BSL-1 have no known potential to cause disease in humans or animals. All live cultures in the laboratory fall into the BSL-1 category. Reference can be made to the CDC's Office of Health and Safety for complete descriptions of the BSL's in the text of the publication Biosafety in Microbiological and Biomedical Laboratories. 3rd edition, HHS Publication No. (CDC) 93-8395, US Department of Health and Human Services, Centers for Disease Control and Prevention, US Government Printing Office, Washington, DC, 1993.

Table 7-10. Results of the BioScan™ for Mahoning River**Project Name:** Mahoning River Bioremediation**Project No.:** G-221**Date Samples Collected:** 5/30/2003-6/1/2003**Contaminants:** (see analytical data)**Date Tubes Read:** 6/14-6/15/03 **Analyst:** Susan Jones **Date Checked:** 6/16/03 **Checked by:** Jo Davison

Microbe	Medium	Target Products/Function	Model Reach				Recovering Area				Test Site			
			Water Interface	River	Ecotone	Riparian	Water Interface	River	Ecotone	Riparian	Water Interface	River	Ecotone	Riparian
Laboratory Measurements														
TPC	TPC	Total Plate Count	3+	3	3+	3+	3+	3	3+	3+	3+	3	3+	3+
TFM	TFM	Total Fungi & Molds	3+	3+	3+	3+	3	3	3+	3+	3	2	2	2
LA	AG/SW	Indicator Algae	1+	2+	2	1+	2+	2	2	2	2+	2	2	2
LP	HW/PP	Indicator Protozoa	2-	2	1	1-	2	2	2	2	2-	2-	2-	2-
BH	BH	TPH/HCO Degraders	1	2-	2	1	2	2+	2-	2-	2	2-	2-	1
LB 7ab	295	NH4 Deg, SO4 Red., Chelates Metals	1	2	3	3	2+	2+	2+	2+	2	2	2	2
LB 48b	480	N3-N2, Chelates Metals	1+	2+	3	3	2	3	2	3	2+	2	3	3
LB 13gg	LM 13gg	N2 Red, Chelates Metals, Oxidizer	1	2	3	3	3	3	2	3	3	2	3	3
LB 43a-h	42	SO4 Deg, Deg. Chloronated, Oils	3	3	3	3	3	3	2+	3	3+	2+	2+	2+
LB 29a	N-11	H2S Deg., Chloronated, SO4 Red	2	3	3	3+	3	3	3	3+	3	3	2+	3
LB 102a	1246	Chelates Metal, Cd, Hg, Zn, As, Cr, Ni, Pb, Va	2	2+	3	2	2+	3	2+	2+	2	2+	3	3
LB 13xx	166	Benzene, TOL, E.B. Benzo(a)pyrene	2+	3	3	2+	3	3	3	2+	3	2+	2+	2+
LB 13LL	13LL	TOL, TCE, Catechol, Ethylene, glycol	1	1+	2	2	2	2	2	2	2+	2	2	2
LB 13z	LM 13z	E.B., Naphalene, anthracene	2+	3	3+	2+	3	3	3	3+	3	3	3	3
LB 17v1-3	LM 17v	Xylene, TPH, Benzene, TOL, Aromatics	2	3	3	3+	3+	3	3	3	2+	2+	3	3
LB 50b	1573	MTBE, Methanol, Haloalkanes, Ethanol	2	2+	3	3	2+	3	2+	2+	2+	2+	3	3
LB 13p	LM 13p	Catechol, Phenols, Ethylalanine, TPH	2+	3	2+	3	3	3+	3	3	2+	2+	3	2+
LB 277	1/10 of 18	Vinyl chloride, Chloroethylene	2+	3	3	3+	3	3	3	3	3	3	3	3+
LB 34ddd	34ddd	Binds out Chlor., TCE, PCB, E.B.	2+	3	3	2+	3	3	3	3	3	3	3+	3+
LB 27f.g	LM 27f	Deg. PCB, Alaphatic HCO	3	3	3+	3+	3+	3+	3+	3+	3+	3	3+	3+
LB 13ddd	1694	Deg. PCE, TCE, C, Chlorobenzene	2	3	3+	3	3	2+	3	3	3+	3	3+	3
LB 50a	221	Deg. TCE-TCA, Phenols, Alkanes, Acetate	2	2	3	3	2	2+	3	3+	3	3	3+	3
LB 13e	LM 13e	Deg. DCE-DCA, TCE, Sludge, TPH	2	3	3	3	3	3	3	3	3+	3	3	3

Microbe	Medium	Target Products/Function	Model Reach				Recovering Area				Test Site			
			Water Interface	River	Ecotone	Riparian	Water Interface	River	Ecotone	Riparian	Water Interface	River	Ecotone	Riparian
LB 12g	1231	Deg. FOGs, Paraffin, Oleagous mat	2	3	3+	3+	3	3	3+	3+	3+	3+	3+	3+
LB 13pp	LM 13pp	Deg. SVOCs, Benzo(a)pyrene	3+	3	3	3	3	3	3+	3	3	3+	3	3+
LB 34c, 8j	LM 38j	Deg. Phenols, Aromatics	2+	3	3	3	3+	3+	3+	3	3+	3	3	3
LB 192a	1690	Deg. Biphenols	2+	3+	3+	3+	3	3	3+	3	3	2+	3+	3+
LB 14a	LM 14a	Deg. Halogens	2	2+	2	2	2+	2+	2	2+	2+	2+	2	2
LB 18g	LM 18g	Enhances Co-metabolism	2+	3	3+	3+	2+	2+	3	3	3	3+	3	3+
LB 33a	LM 33a	Deg. Alaphatics	3	2+	3	2+	3	3	2+	3	2+	3	3	2+
LB 52f	1120	Deg. Ethylenes	3	3	3	2+	3	3	3+	3	3	3	3	3+
LB 191	N-31	Deg. Acetates	2	3	3+	3	3	2	3	3+	2+	2+	2+	3
LB 13c	LM 13c	Deg. Pesticides	2+	3+	3+	3+	3	3	3	3+	3+	3	3+	2+
LB 110a1-3	LM 110a	Deg. Fluorinated Compounds	1+	2+	2+	2+	2+	2+	2+	2+	2+	2	2+	2+
LB 228g	1306	Methanogenesis	1+	2+	3	3	3	2+	3	3+	2+	2+	2+	3+
LB 4b	756	Fixes CO2	2	3	3	3	3	3+	3+	3+	3	3	3+	3+
LB 27c	1687	Deg. Herbicides, Oxidizes PAHs	2	3	3+	3	2+	2+	3	3	2	2	3	3
LB 89a	LM 89A	Deg. Phthalates	3+	3+	3+	3+	3+	3	3+	3+	3	3+	3+	3+
LB 10A,D	12	Deg. Glycols	2	2+	3	2+	2+	3	2+	3	2+	2+	3	3
LB 13xx	166	Produces Surfactants	3	3	2+	3	2+	2+	3	3	2+	3	3	3
LB 170-2	LM 17d	Deg. Furans	3	3+	3+	3+	3	3	3	3+	3	3	3	3+
LB 17T-1	LM 17T	Deg. CN	2	2+	3	3	2+	2+	2	2+	2+	2+	2+	3
LF 14a-d	343	Fixes PO4	2+	2+	2	2	2+	2	2	2	2	2	2	2
LB 94b,c	LM 94c	Fixes N2	2+	3	3	3	3	3	3	3	2+	3	3+	3
LF 3	200	Fixes K	2	2	2	2	2	2	2+	2+	2	2	2	2
LB 17i	620	Deg. CH4	2	3	3	3	2+	2+	2+	2+	2+	2+	2+	2+
LA 24	940	Oxidizes Organic Substances	2+	2	2	2	2	2	2	2	2+	2	2	2
LB 31a-d	550	H2 Fermentation	1+	2+	2+	3	2+	3	3	2+	2	2+	2+	2+
LB 123	SP432	Controls Blue-Green Algae	2+	2+	3	2+	2+	2+	2+	2+	2+	3	3	2+
LP 15	357	Assimilates CO2	2	2	2+	2	2	2	2	2	2	2	2	2
LF 117a	LFM 117a	Deg. TNT, DOT, Azodyes, Lionin, PCBs	2	2	2	2	2	2	2	2	2	2	2	2

Note:

LB = Bacteria, LA = Algae, LF = Fungus, LP = Protozoa

Figure 7-1. Lambda Staff Preparing Growth Media for MicroEcological Profile™



Figure 7-2. View of the Growth Media and Nutrient Collection at Lambda's Laboratory



Table 7-11. Results of the MicroEcological™ Profile for Mahoning River**Project Name:** Mahoning River Biotreatability Study**Project No.:** G-221**Date Samples Collected:** May 31-June 2, 2003**Contaminants:** (see analytical data)**Date Tubes Read:** 8/11-8/13/03 **Analyst:** S. Jones

LB = Bacteria, LA = Algae

Date Checked: 8/11-8/13/03 **Checked by:** J. Davison

LF = Fungus, LP = Protozoa

Microbe Bacteria	Test Site				Microbe Bacteria	Test Site			
	Soil/ Water	River	Ecotone	Riparian		Soil/ Water	River	Ecotone	Riparian
LB 3a-e, 5a-c	3	2	3	2+	LB 17v1-3	Bioscan			
LB 4b, 148	Bioscan				LB 17w	2+	2	2+	3
					LB 18g	Bioscan			
LB 10a,d	Bioscan				LB 26	2+	2+	2+	2+
LB 12aa	3	2	3	3	LB 27c,m,181b	Bioscan			
LB 12aaa, bbb, ee, z	3	2	3	3	LB 27e,34uu,v v, 89y	2	2+	2+	2
LB 12c	3	2	3	3	LB 27f,g	Bioscan			
LB 12cc	3	2	2	2	LB 27L	2	2	2	2
LB 12dd	2+	2+	3	3	LB 28a-f	2+	1+	2+	2
LB 12g,t	Bioscan				LB 29a-f	Bioscan			
LB 12k,ii-tt	3	2+	3+	3	LB 33a,31a,c,d	Bioscan			
LB 12yy	3+	3+	3+	3+	LB 34bb	2	1	1+	2
LB 12v-z	3	3	3	3	LB 34c	Bioscan			
LB 13aaa	3	2+	2+	3	LB 34cc	2	2	2+	2+
LB 13c	Bioscan				LB 34ddd,eee	Bioscan			
LB 13d	1+	2	2	2	LB 34fff	2+	2+	3	3
LB 13dd	3	3	3	3	LB 34kk	3	2+	3	2+
LB 13ddd	Bioscan				LB 36a,b	3	2+	3	2+
LB 13e, 17ii-1-2	Bioscan				LB 38a,d,g	3	2+	3	3
LB 13eee	3+	2	2+	3	LB 38b,e	3	3	2+	1+
LB 13fff	3	3	2+	3	LB 38n	2	2	3	3
LB 13gg	Bioscan				LB 41a, d, 104d, 228e,f	2+	2	3	2
LB 13ggg	2+	2	2	2	LB 41b	3	3	3	2+
LB 13hhh, 36c, 178a	2+	3	2+	3	LB 43a-h	Bioscan			
LB 13iii,jjj	3	3+	3+	3+	LB 48a	3	1+	1+	2
LB 13LL	Bioscan				LB 48b	Bioscan			
LB 13n	2+	2	3	3	LB 50a	Bioscan			
LB 13p	Bioscan				LB 50b	Bioscan			
LB 13pp,ss, 34aa	Bioscan				LB 51a	1+	1+	1	2
LB 13v,34i	2	2+	2	2+	LB 51b	2+	1+	2	2+
LB 13v v	3	2+	3	3	LB 52e	3	2+	3	3
LB 13w	3	3	3	2+	LB 52f	Bioscan			
LB 13xx	Bioscan				LB 62c	2	1+	2	3
LB 13y	2-	2	2	2	LB 89a	Bioscan			
LB 13z	Bioscan				LB 89n	2	2	3	3
LB 14b,bb,c, cc,dd,61d,l,m,o,p, 92fff,ggg,hhh,97b ,e,163,169a,187	2	2	2	2	LB 90c	3	2	3	3
LB 17b1	2+	2+	2+	2+	LB 92aa, p, s, u	3	2	3	3
LB 17d-1,2	Bioscan				LB 92c,142b	3	2+	3	3
LB 17k,ff	2+	2	2	2+	LB 92d	3	2+	2+	2+
LB 17t	Bioscan				LB 92e-i, 14aa,14L	2	1+	1+	1+

Project Name: Mahoning River Biotreatability Study**Project No.:** G-221**Date Samples Collected:** May 31-June 2, 2003**Contaminants:** (see analytical data)**Date Tubes Read:** 8/11-8/13/03**Analyst:** S. Jones

LB = Bacteria, LA = Algae

Date Checked: 8/11-8/13/03**Checked by:** J. Davison

LF = Fungus, LP = Protozoa

Microbe Bacteria	Test Site				Microbe Fungus	Test Site			
	Soil/ Water	River	Ecotone	Riparian		Soil/ Water	River	Ecotone	Riparian
LB 92k-m	1+	1+	2	2+	LF 117a	Bioscan			
LB 92zz	1	1	2	2	LF 117b	2	2	1+	1+
LB 94b,c	Bioscan				LF 117c	2	1+	1+	2
LB 101a	3	2	3	3	LF 118a	2+	1	2+	2
LB 102a	Bioscan				LF 119a,b	2	2+	2+	2
LB 102g	3	2+	3	3					
LB 109e-h	3	2-	3	3					
LB 110a1-3	Bioscan								
LB 110b	3	2	3	3					
LB 110d-i	3	2+	3	3					
LB 131b	2+	1+	2+	2					
LB 133a	2	2+	2	2+					
LB161a,b,228b	2	1+	3	2+					
LB 191	Bioscan								
LB 192a	Bioscan								
LB 228g	Bioscan								
LB 273a	2	1+	2	2+					
LB 273b	3	2	3	2+					
LB 277	Bioscan								
LB 278	3	3	2+	2+					
LB 279	2+	2	2+	3					
LB 280	3	1	3	3					
						Page Number: 2			

Project Name: Mahoning River Biotreatability Study**Project No.:** G-221**Date Samples Collected:** May 31-June 2, 2003**Contaminants:** (see analytical data)**Date Tubes Read:** 8/14 – 8/18/03**Analyst:** S. Jones

LB = Bacteria, LA = Algae

Date Checked: 8/14 – 8/18/03**Checked by:** J. Davison

LF = Fungus, LP = Protozoa

Microbe Algae	Test Site				Microbe Protozoa	Test Site			
	Soil/ Water	River	Ecotone	Riparian		Soil/ Water	River	Ecotone	Riparian
LA 2a-p	2	2	2	2	LP 3a-f	2	1+	1+	1+
LA 3	1	1+	1+	1	LP 4a,b	1	1	1+	1+
LA 4	1	1	1	1	LP 5	2	1	1	1+
LA 5	1	1	1+	1	LP 6	1+	1	1	1
LA 6	2	1	2	1	LP 7a-e	2	2	1	1
LA 8a,b	2	1+	2	1	LP 8	2	1	1	1+
LA 9a,b,c,d,e	1	1	1+	1	LP 9	2	1	1	1
LA 11	1+	1+	2	1	LP 10a-c	1+	1	1	2
LA 13	1	1	1	1	LP 11a,b	1+	1	1+	1+
LA 14	1	1	1+	1	LP 12	2	1	1+	2
LA 15	1+	1	1+	1	LP 13	2	1	1	1+
LA 16	1+	1+	1+	1+	LP 14a,b	1	1	1	1
LA 17	1+	1	1+	1	LP 15	Bioscan			
LA 18	1+	1	1+	1	LP 17a,b	1+	1	1	1
LA 19a-e	1+	1	1+	1	LP 19	1	1	1+	1+
LA 20a-d	1	1	1	1	LP 20	1+	1	1	1+

Microbe Algae	Test Site				Microbe Protozoa	Test Site			
	Soil/ Water	River	Ecotone	Riparian		Soil/ Water	River	Ecotone	Riparian
LA 22a,b	1	1	1	1	LP 21	1	1	1+	1
LA 23	1+	1	1+	1					
LA 24	Bioscan								
LA 25	1+	1	1	1					
LA 26	1	1+	1	1					
LA 27	1	1	1+	1					
LA 28a,b,c,d	1	1	1+	1					
LA 30	1+	1	1+	1					
LA 31	1+	1+	1	1					
LA 32	1+	1	1	1					
LA 34	1	1	1+	1					
LA 35	1	1+	1	1					
LA 36	1	1	1	1					
LA 37a,b	1+	1	1+	1					
LA 38a,b	1	1	1	1					
LA 40	1+	1	1	1					
LA 41a	1	1+	1+	1					
LA 46	1+	1	1	1					
Page Number: 3									

7.2.3 Summary of Findings

The BioScan™ compared the population density and viability of each of the key microbes in the Model Reach, the Recovering Area, and the Test Site. The density and activity level of the key microbes generally were higher in the Recovering Area and Test Site because the COCs are at a lower level in the Model Reach because the COCs are a food source for the key microbes. When the food source decreases, so do the populations. A total of 612 microbes were tested for in the BioScan™, 528 bacteria, 48 fungi, 24 algae, and 12 protozoa.

The MEP™ is a more in-depth look at the Test Site microbial communities. The populations are unbalanced and the algae and protozoa are almost non-existent there. The levels of the COCs are high enough to cause a toxic shock reaction in most of the microbes, except those with thick slime coats or the ability to form impervious spores under environmental duress.

Lambda followed strict quality control measures to ensure the accuracy of the results of the BioScan™ and MEP™. Ten percent of all readings were performed in duplicate by a second person. One hundred percent of the readings were checked for accuracy by Jo Davison, Research Director.

SECTION 8.0 CONSORTIUM FORMULATION AND INOCULATION

Once the BioScan™ and MEP™ were completed, the consortium was designed. A microbe was included for each step of each remediation for all contaminants. Supplemental microbes also were included to provide the support needed by the primary microbes, such as providing enzymes, controlling interfering processes, and adjusting soil chemistry to be more favorable to

the process. In all, a total of 361 microbes were used in the consortium, 233 bacteria, 35 algae, 16 protozoa, and 77 fungi. Five new type cultures were purchased to complete the inventory of microbes and to hybridize the indigenous bacteria: BAA-498 *Mycobacterium* sp., BAA-499, *Nocardioides* sp., BAA-500 *Polaromonas* sp., BAA-423 *Ralstonia* sp., and 12633 *Pseudomonas putida*. All were BioSafety Level 1.

8.1 ACCLIMATION

Lambda's acclimation process was developed by Lambda and is proprietary. It is a method for utilizing special foods, enzymes, vitamins, and minerals, a type culture of the microbes and the microbes cultured from the site to build a consortium. Until a hybrid of the microbe is produced through natural acclimation, it is difficult for the microbes to withstand the stress imposed on them by the high concentrations of COCs in the Test Site. It was very difficult to get the hybrids acclimated to grow in the Mahoning River soils and water, but a balanced microecosystem in the growth tank was achieved. Additional funding for the purchase of all the required cultures, enzymes, and vitamin mixtures to strengthen the hybrids would have made the microecosystem balance more robust and enhanced the degradation of the high concentrations of COCs at the Test Site

Figures 8-1 and 8-2 show Lambda's laboratory in the midst of the acclimation process.

Figure 8-1. The Acclimation Process



Figure 8-2. The Acclimation Process with Growth Tank in the Background



8.2 SCALE-UP

Once the microbes were acclimated to the contamination at the site, they were combined into a large PVC growth tank. This tank was used to propagate the microbes so that enough of a volume of inoculum was grown to be able to treat the entire Test Site. Approximately 400 gallons was grown.

The feed protocol is based on the site chemistry taken along with the data on the COCs. During scale-up, we needed to increase nutrients that were site-deficient and use less of those nutrients that were adequate or high (not many fell into the latter group). We also had to balance the pH and produce an environment that was friendlier to facultative anaerobes, methanogenic bacteria, fungi, algae, and protozoa. It is a difficult balance to achieve. Food is added twice weekly at five times the normal rate and grab samples are taken and read three times a week to check the population density, viability, and diversity. Based on 20 years of professional judgment, microbe density, viability, and robustness, the consortium is deemed ready to be delivered to the site. Because it is a viable culture, delivery must be carried out within a few days, once the consortium is transferred to a transport tank.

BioCarb™ bags were prepared by filling 30-pound permeable bags with granular, activated carbon. The bags were then soaked for two days in the inoculum so the microbes adsorbed onto the carbon particles. These bags were used under water to hold the inoculum in place and to release the microbes over time into both the water and underlying sediments, serving as small bio-reactors.

8.3 TEST SITE INOCULATION

Four hundred gallons of inoculum and 24 saturated BioCarb™ bags were installed at the site. There were 30 injection points. Site inoculation was accomplished in a single day, October 4, 2003. Inoculum was applied in a number of ways; 1) the consortium was injected into pre-drilled holes in the ecotone and the riparian zones, 2) the ecotone and riparian zones were sprayed with inoculum at the end of the day, 3) extra BioCarb™ bags (6) were opened and the treated carbon was placed into the on-shore holes, 4) pressure injection was used to inoculate the river zone into soils below the water, and 5) BioCarb™ bags were laid on the river bottom. A copy of the OEPA's Permit to Construct is included as Appendix E to this report.

Site Preparation: Site preparations for the inoculation took place on September 3, 2003. The Test site was prepared by staking out the corners of the plot and using field equipment to clear the vegetation in the Test Site. Large trees were left, but ground cover, which was abundant, was removed. Although treatment could have occurred without clearing the site, this preparation was deemed necessary for several reasons: 1) the timeframe of the study required that the inoculum reach and cover the ground as quickly as possible and this was thought to be facilitated by removing the vegetation, 2) intensive field inoculation and subsequent sampling would be easier without the encumbrance of thick vegetation, and 3) site visitors were expected and there was a reduced chance of tripping and exposure to poison ivy if the site was cleared first. Figure 8-3 shows the Test Site prior to site preparation.

Figure 8-3. Test Site Prior to Grubbing



Marking the Grid: Wooden stakes were driven at the corners of the onshore zones and rebar poles, 10 feet long, were driven into the two corners of the Test Site in the river. A tape was used to measure the cells for the onshore zones and utility flags were placed at the onshore

injection ports. A rope was strung along the boundary between the ecotone and river zones. The location of the injection points was measured using a tape to locate the center of the cells in the ecotone, the cell nodes in the river, or the mid-point of the eastern edge in the riparian zone. As the injection in the river sediments progressed, each distance from shore was measured by a tape suspended from the shore onto the river. Once an injection was complete in a river cell, the BioCarb™ bag was placed and then the team moved on to the next cell. Other than the two rebar markers, no markers were left in the river.

Inoculation Target:

- a) river sediments – Injected from 0 to 2-foot depth, maximum 16 feet from shore, 60 gallons per 8-foot strip
- b) ecotone sediments – injected from 3 to 5-foot depth, from shore to 16 feet up the bank
- c) riparian sediments – injected from 4 to 6-foot depth, near the interface with the ecotone (eastern edge of riparian zone)

Spacing on shore – The ecotone and riparian zones were each 16 feet wide (east-west) and divided into 8 cells, each approximately 6 feet long. Injection in the ecotone was performed at center of each cell. Injection in the riparian zone was at eastern edge of each cell, because the initial sampling did not detect significant contamination in the center and farther west. Each cell received approximately 6 gallons of inoculum.

Spacing in river – Twenty-four BioCarb™ bags were placed on the river bed, from the shore to a distance of 16 feet from the shore. Bags were placed in three rows consisting of eight cells each, the first row at the shoreline, and the second and third rows at distances of eight and 16 feet from the shore.

The layout of the injection and bag placement is shown in Figure 8-4. A schematic of the inoculation is shown in Figure 8-5.

Spray target – Inoculum was sprayed onto the river banks in the ecotone and riparian zones, all remaining inoculum was used. After spraying, extra BioCarb bags were opened and their contents spread on the ecotone and riparian zones.

Injection Holes On Shore - Holes in the riparian and ecotone were pre-drilled by driving a geostick (solid metal probe six feet in length and approximately two inches in diameter with a pointed end and flat top) with a hammer to the desired depth of injection.

Inoculation Rate and Methods: Four hundred gallons of inoculum were used at the site. Injection in the pre-drilled holes and in the upper 6 inches of the river sediments was accomplished using a jetting probe. Two were available, 6 feet and 8 feet long. The probes consisted of a hollow stainless steel wand with a hole and deflector in the end. The inoculum was under a pressure of 125 psi (pounds per square inch), which caused the inoculum to spray out of the hole in a fan shape. This allowed the injection to be directed and prevented the wand from clogging with soil. The probe was inserted into the subsurface to the desired top of the target depth and then inoculum was delivered under pressure (approximately 6 gallons per hole for a total of 180 gallons). The probe was moved so it advanced to the depth equal to the bottom of the target zone. The pressure was turned off and the probe withdrawn. The quantity of inoculum was monitored by watching the graduations marked on the side of the 200-gallon tank. Onshore, only one injection point in each cell received inoculum. Offshore, as many shallow points of injection were inoculated in each cell until the 6-gallon allotment would allow

(using approximately 145 gallons). The injection was at the rate of approximately 2.5 gallons per minute. The overall application rate was between approximately 6500 and 7000 gallons per

Figure 8-4. Configuration of the Inoculation Layout

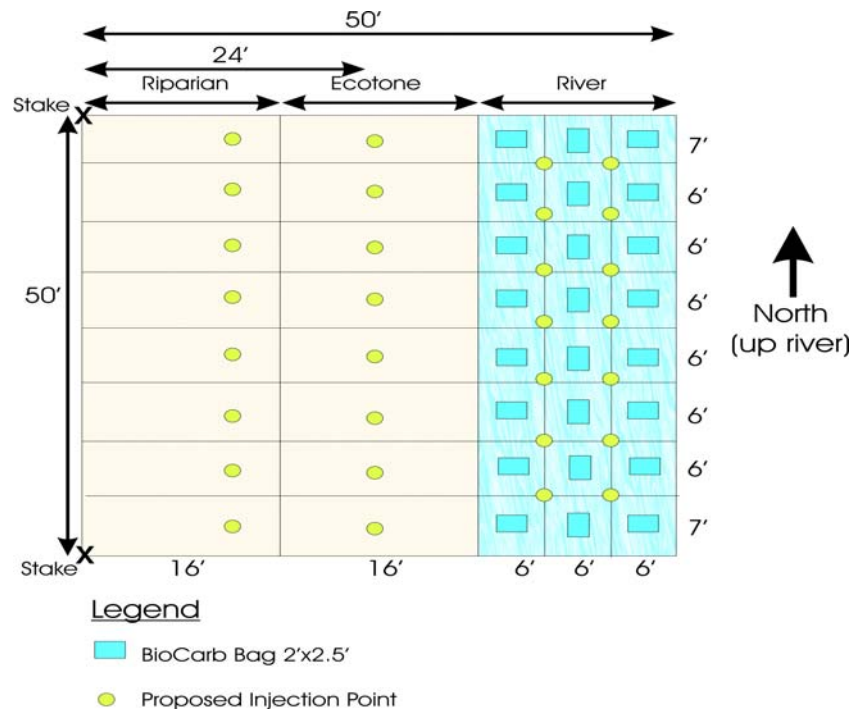
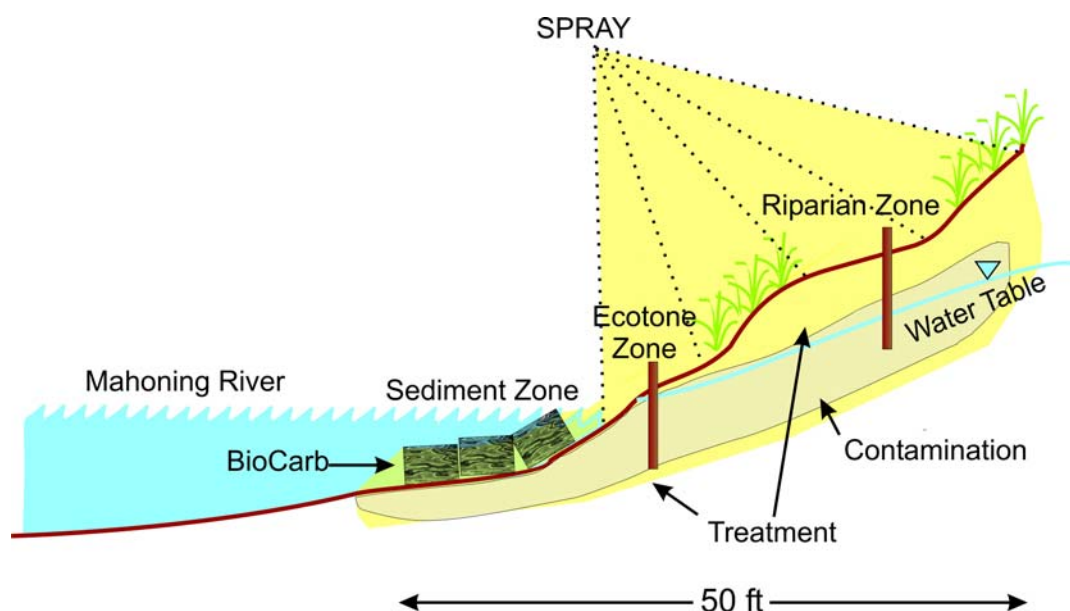


Figure 8-5. Schematic of the Inoculation of the Test Site



acre. The remaining 75 gallons of inoculum was sprayed on the surface of the ecotone and riparian zones.

BioCarb™ bags were placed in the two rows of cells nearest the shore using chest waders. The bags were placed after the injection was completed. A boat, provided by the Corps of Engineers, was used to place the bags in the row of cells farthest from the shore.

Health and Safety Monitoring: No breathing zone monitoring was conducted, as per the decision of the Site Safety Officer. The rationale behind this decision was that no organic vapors above health thresholds were detected during the initial sampling, so no sampling or drilling took place during inoculation.

Decontamination: Personnel decontaminated themselves as per the Safety and Health Plan. The injection probe was wiped between injections, but was not decontaminated. The rationale behind this decision was that no sampling was scheduled to take place for six weeks, the injections were implemented from the least contaminated to most contaminated (riparian to river) zones, and the injection points are in close proximity to one another, especially in the river.

**Figure 8-6. Inoculation of the River Zone
(BioCarb™ Bags in the Foreground)**



Figure 8-7. Inoculation of the Ecotone



Figure 8-8. Inoculation of the Riparian Zone



SECTION 9.0 EFFECTIVENESS SAMPLING

9.1 CLEANUP TARGETS

The complete cleanup of the Test Site will be achieved when all targets COCs are detected at concentrations at or below those concentrations found in the Model Reach at the end of the remediation period. Tables 7-2 through 7-7 show these target concentrations for each zone for every detected analyte, as indicated in green and labeled "Model Reach."

9.2 DATA LIMITATIONS

For the purpose of data analysis and due to the limited number of samples that were collected for effectiveness monitoring, the results for each sampling event were averaged separately in each zone. Thus, the average final concentration of arochlor 1260, for example, is a single number in the riparian zone, a single number in the ecotone, and a single number in the river, even though multiple samples from each zone were sometimes collected. This was done for each analyte. (See comparison Tables 9-1 through 9-5.). The effect of this averaging is more pronounced for samples that exhibited a great disparity between the riparian and river zones, for example. Recovering Area sample results are not included in the comparison tables. Samples from the Recovering Area were primarily collected to design the consortium and do not present any meaningful comparison to evaluate the effectiveness of the remedy. Therefore, the comparison tables only present the Model Reach as compared to the initial, interim, and final sample results. The full set of analytical results is presented in Appendix A.

A concern regarding the data evaluation centers around interpreting the analytical results where there are values below the quantitation limit (BQL). This means that the analyte was not detected above the BQL, but is probably not zero. A careful examination of Tables 7-2 through 7-7 shows many results are termed BQL, with a wide variety of detection limits. One standard way of factoring the detection limits into the analysis of the results is to assign each BQL the value of half the associated detection limit. So, if a BQL was associated with a detection limit of 1200, a value of 600 could be assigned. This is often done because graphing and statistical analyses cannot incorporate non-numerical values. However, in many of the cases where quantitative results were far less than some of the detection limits for samples in the same zone, using half the detection limit would significantly bias the average and would not allow a meaningful comparison of the data. This is true for all analytes except pesticides. As an example, the results for the final samples in the ecotone for benzo(ghi) perylene are as follows:

Result 1	1100
Result 2	1600
Result 3	1800
Result 4	BQL (<6700)
Result 5	820
Result 6	BQL (<6200)

In point of fact, one does not know how much below the detection limit the BQL values represent. If the average is calculated using half of the detection limit, the average is calculated to be $(1100+1600+1800+3450+820+3100)/6$ or 1978. This is clearly higher than any quantitative value detected in this zone for this analyte, and is not a fair representation of the average. However, if the average is calculated without using the detection limits, one would calculate an

average of (1100+1600+1800+820) or 1330. This second number is clearly more representative of the actual values detected from the zone. This second method was used to calculate all averages presented in the table and graphs in this section of the report. The only exception is for pesticides. Because the detection limits for pesticides were low and usually the same order of magnitude when compared to the quantitative values, averages for pesticides were calculated using the first method, half the detection limit.

The final concern regarding data interpretation is simply the paucity of data. Meaningful comparisons cannot be made when using a single data point to represent conditions at a site. It is particularly significant in making comparisons using single interim sampling data points.

9.3 ANALYTICAL CONCLUSIONS

Some general conclusions can be drawn from the sampling results before and after treatment. Details for individual sets of parameters are found in the following sub-sections 9.3.1 through 9.3.5 of this report.

1. Sampling confirmed that only minor contamination was found in the Model Reach, in all three zones (river sediments, ecotone, and riparian). Among the contaminants detected in the Model Reach were leachable manganese (from 307 to 5130 ug/L), leachable zinc (from <200 to 1540 ug/L), and TPH (from <30 to 93 mg/kg). Other analytes were detected in the Model Reach, but none were identified as COCs.
2. Model Reach standards were evident for many constituents in at least one of the three zones of the Test Site over the five-month treatment period, but they were evident in ALL three zones for the pesticide gamma-chlordane, leachable metals arsenic and chromium, and PAHs acenaphthene and naphthalene.
3. Generally speaking, PAHs responded most dramatically to bioremediation, with decreases in the 16 compounds detected of between 15 and 70% below initial concentrations. No averages exhibited an increase between the pre-treatment (initial) and post-treatment (final) sampling events.
4. Analytical results were most dramatic for the interim (six-week) samples for almost all constituents (except leachable zinc, which was higher after six weeks). Several reasons for this sudden decrease and subsequent relative increase in concentrations might be: a) the period between the initial and six-week sampling was relatively warm and better suited for the microbes. Contamination may have migrated during the winter while the microbes were relatively dormant, resulting in increases after six weeks; b) only one sample during the six-week sampling event was analyzed for the majority of the COCs. This one data point is not a statistically defensible basis of comparison, which is why the interim samples, although shown on the graphs, were not included in the calculations that quantified success; c) spatial variability between the sampling point might account for some of the differences in concentrations.
5. Surface and near-sediments in the river zone were the most difficult to clean. In fact, numerous constituents may have increased in this zone from pre- to post-treatment sampling, including PAHs dibenz(a,h) anthracene, naphthalene, acenaphthene, acenaphthylene, and anthracene; pesticides 4,4-DDE, 4,4-DDT, alpha-chlordane, dieldrin, and endrin; leachable metals barium, iron, and nickel. This suggests several possibilities: a) because the Test Site is in an area of deposition,

contaminated sediments upstream of the Test Site may have re-contaminated the river sediments during the winter and spring thaw or during flooding; b) the duration of the study was not long enough to realize an overall reduction in the river zone, and the response may have been delayed due to the initial high concentrations found there; c) the use of BioCarb™ bags and pressure injection may not have been sufficiently rigorous to address the contaminated sediments in that zone; d) the limited number of samples and the observable high variability in some of the chemistry may have resulted in an aberrantly high final sample at one location, skewing the average; and e) spatial heterogeneity may account for some of the differences in the analyte chemistry.

6. The appearance of lighter aroclors 1232 and 1254 were none were previously detected and the disappearance of arochlor 1260 in river sediments could most likely be interpreted as the partial biodegradation of arochlor 1260. Slight increases in the two other zones is likely the result of sampling variability. The conclusion that can be drawn is that the process is working, but incomplete.
7. It is evident that the use of bioremediation is sensitive to the season in which the inoculation takes place. Inoculation should be based on biology rather than project management considerations. The best time to inoculate is in the spring, when the leave cover does not inhibit sprayed inoculum from reaching the soils, when the ground is not frozen and can be penetrated easily, and when inoculation is followed by many months of warm weather to provide the most suitable conditions for the microbes to be active.

9.3.1 PCBs

Figure 9-1 presents the summary of analytical results for PCB aroclors 1232, 1254, and 1260 over time. No other aroclors were detected in any of the samples collected for this study. All arochlor concentrations were below the detection limits in the Model Reach. During the initial sampling, only arochlor 1260 was detected, in the ecotone at 150 ug/kg and in the river sediments at 180 ug/kg. The interim sample, which was only collected in the ecotone, exhibited a concentration of 34 ug/kg, a 77% decrease. This dramatic interim decrease was typical of many of the analytes of this study. The final sampling event detected two new lighter aroclors (1232 and 1254) in the river, although arochlor 1260 dropped to below detection in that same sample. Arochlor 1260 was detected for the first time in the riparian zone at 14 ug/kg and again in the ecotone at a concentration of 210 ug/kg. Figures 9-1 and 9-2 show these results graphically. Total detected average PCBs concentrations are summarized below. It should be noted that, although total PCBs are used throughout the river study area to indicate magnitude of contamination, the fact that they are being transformed through biological processes is not taken into account by representing the data in this way.

<u>Average Concentration</u>	<u>Model Reach</u>	<u>River Sediments</u>	<u>Ecotone</u>	<u>Riparian</u>
Initial	BQL	180	150	22.5
Six Week	N/A	N/A	31.1	N/A
Final	N/A	1196	91.3	20.2

Note: ½ BQL values were used in the averages.

Discussion – PCBs are notoriously difficult to degrade. Aroclor 1260 was detected in the Recovering Zone (from 62 to 190 ug/kg), but no other congeners were detected there. Aroclor 1260 (the heaviest PCB) was the only PCB detected during the initial sampling of the Test Site ecotone and river zones. After treatment, two lighter aroclors were detected (1232 and 1254), both in the river sediments, but the initial concentration of aroclor 1260 (180 ug/kg) was no longer present there. The results of this study do not show a decrease in aroclors in the ecotone or the riparian zones of the Test Site, although the results in the riparian zone are both flagged as questionable and the highest result in the ecotone (390 ug/kg) is also shown with a flag that makes the result questionable. One result in the ecotone exhibited a significant decrease for the original value (from 150 to 21 ug/kg).

The most interesting aspect of the results is the appearance of lighter aroclors. There are two possible explanations for this. First, they only were found in river sediment samples. It is possible that contamination from upstream, in the form of these lighter aroclors, has been deposited at the site during the study period. In fact, this follows a trend seen in many of the river samples. However, the more likely scenario for the river samples is that aroclor 1260, which is no longer present, has been stripped of some of its chlorine atoms during the breakdown caused by the microbes and has been transformed into lighter aroclors as the beginning steps of the multi-step process (see Figure 3-1 for details). Aroclor 1260 increased slightly in the ecotone (from 150 to 210 ug/kg) and appeared in the riparian zone for the first

Figure 9-1. Comparative Concentrations of Aroclor 1232, 1254, and 1260

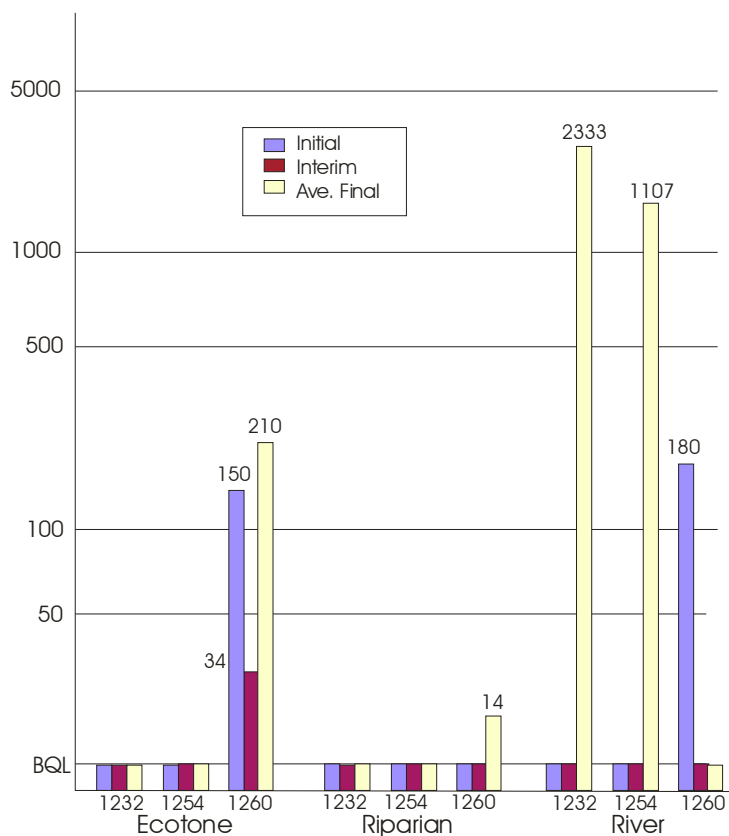
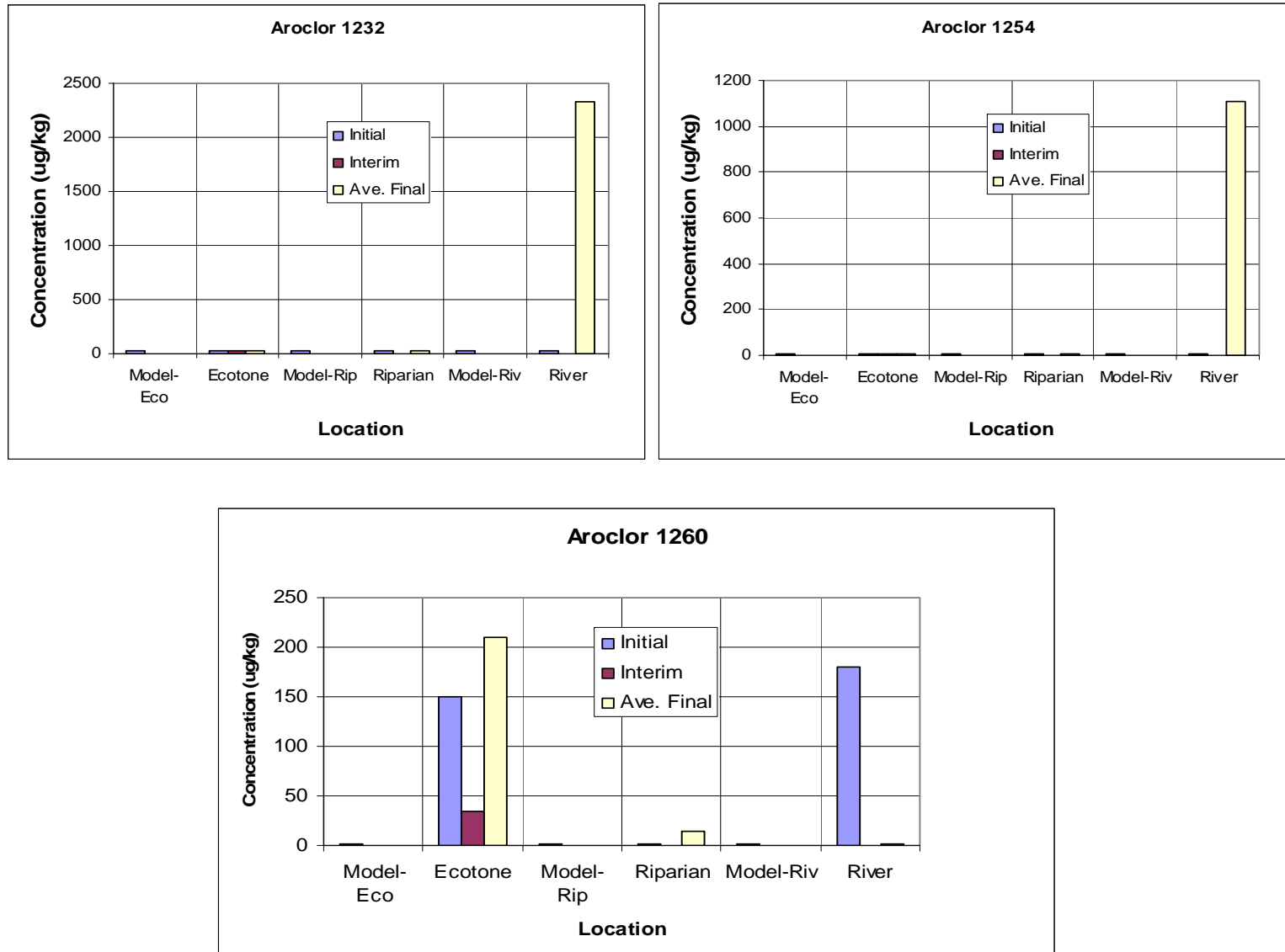


Figure 9-2. PCB Sampling Summary



time post-treatment (14 ug/kg). The most likely explanation for this is sampling variability or re-contamination during spring flooding.

9.3.2 Leachable Metals

Table 9-1 presents a comparison between the cleanup targets for leachable metals in the Model Reach, the interim sampling results, and the final sampling results. Figure 9-3 is a graph illustrating this same comparison. Eight leachable metals, subjected to the TCLP procedure, were detected at the Test Site.

Discussion – It can be seen from Figure 9-3 and Table 9-1 that, of the eight leachable metals detected at the site, three were reduced during the study period: arsenic 15%, chromium 96%, and manganese 40%. Concentrations meet Model Reach conditions for arsenic and chromium. Bioremediation success for heavy metals has been demonstrated in the literature and with Lambda projects over many years. The relative unresponsiveness of the metals to bioremediation simply indicates that five months is not long enough to achieve the desired results.

Individual metals require different processes for treatment.

Arsenic (As) is detoxified by oxidation of the correct enzymes and specialized microbes are used. We had neither, since only As oxidation requires them. As [As III] will occasionally bind to oxidized manganese but the process is repressed by Fe III, which is very high in the test area. Microbes were available to reduce the As and worked in the river and riparian zone. Oxidized AS from the river deposited in the ecotone, causing the increase. It will decrease in time.

Barium (Ba) is a naturally occurring earth metal in soils and surface water. It is normally found as barium sulfate. The microbes will recombine the barium as the sulfate is pulled off and used as energy in the river and ecotone. The addition of sulfate by the microbes will bind it back over time. The SO₄ reducing bacteria were needed for reductive dechlorination.

Chromium (Cr) was successfully reduced by sulfate reducing bacteria and enzymes.

Iron (Fe) became oxidized in the river and the ecotone and must be reduced to detoxify. The dissolved O₂ in the moving water and flooding of the ecotone oxidized the environment and the iron.

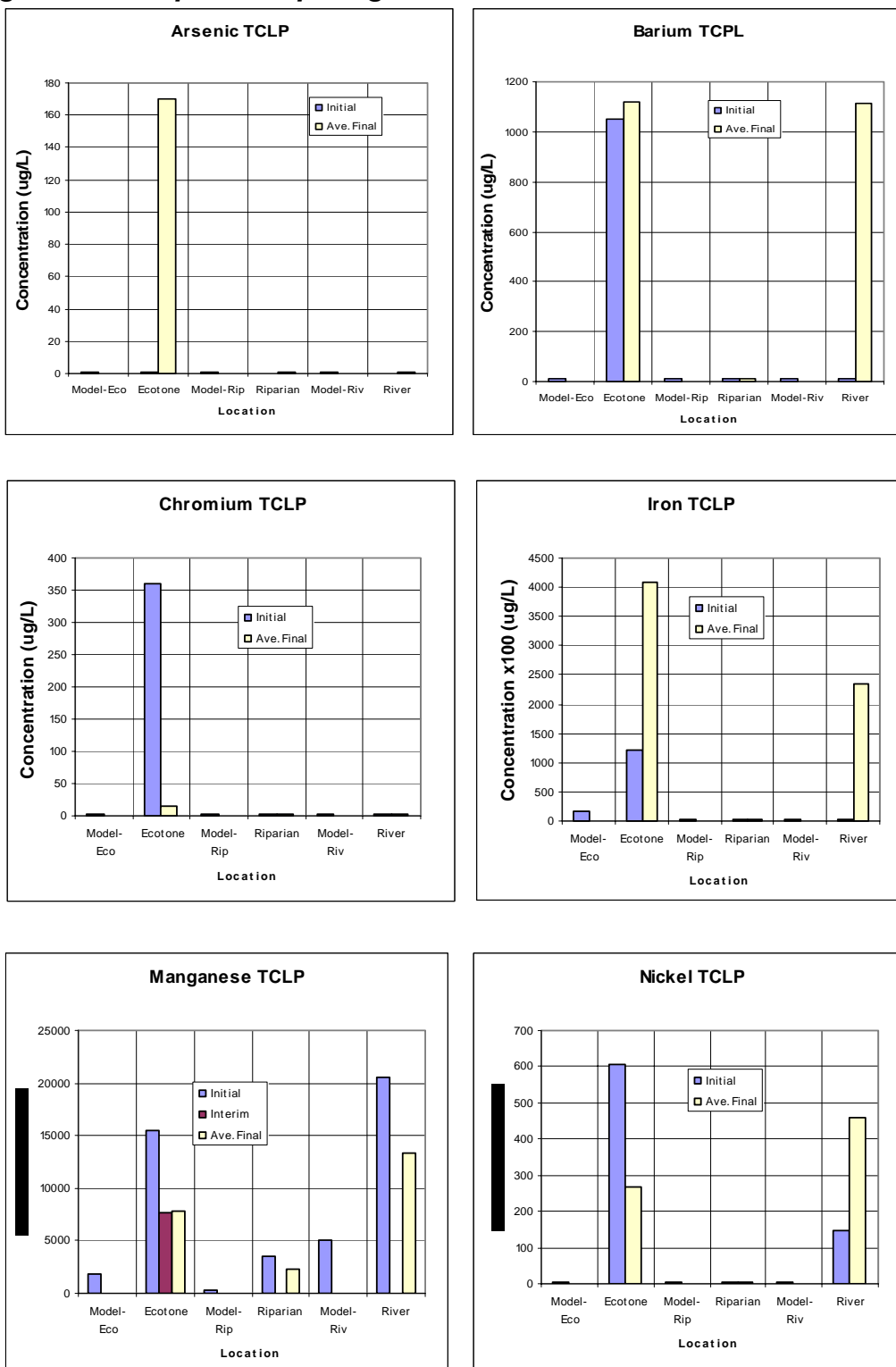
Manganese (Mn) was reduced by the oxidation process that caused iron to increase.

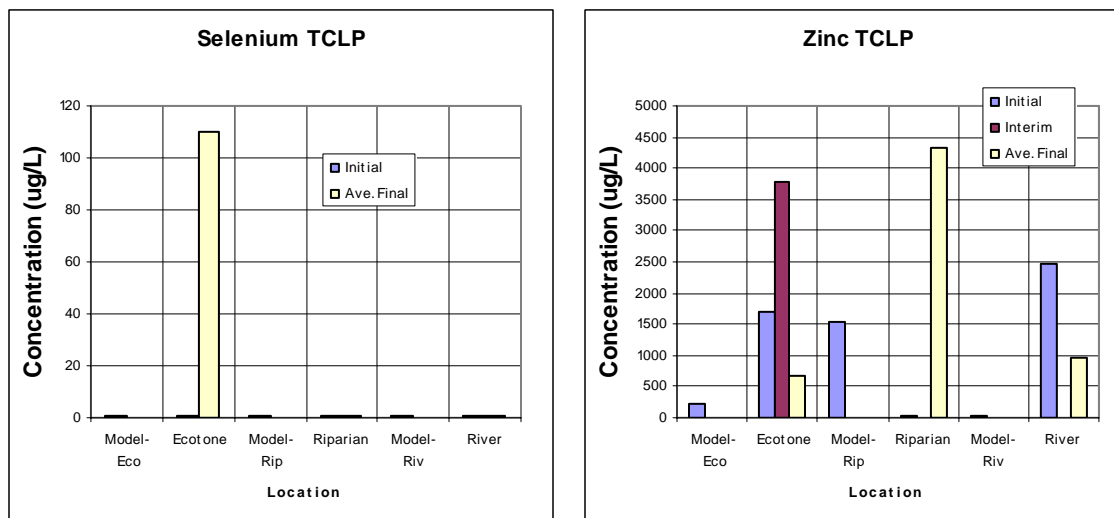
Nickel (Ni) commonly found in steel and electronics industries binds out early in a reducing environment, but reactivates in the oxidizing environment of the river.

Selenium (Se) can be reduced anaerobically by microbes, usually in deep fresh water sediments. Exposure to oxygen by flooding the ecotone can re-toxify this element temporarily.

Zinc (Zn) is found in galvanized pipes. It is a necessary trace element for plants and animals. Flooding into the riparian zone can deposit zinc, but it will detoxify quickly.

Figure 9-3. Graphs Comparing Leachable Metal Results to Model Reach





9.3.3 PAHs

Table 9-2 presents a comparison between the cleanup targets for PAHs in the Model Reach, the interim sampling results, and the final sampling results. Figure 9-4 is a graph illustrating this same comparison.

Discussion - PAHs seemed to respond well to the treatment. Of the 16 compounds initially detected in the samples, 11 exhibited decreased concentrations in all three zones with respect to the initial concentrations. The reductions ranged from 18 to 69 percent, with an average reduction of 45 percent in five months. Acenaphthene and naphthalene were reduced to below Model Reach concentrations in all three zones, and eight compounds were reduced to Model Reach concentrations in at least one of the three zones. Only six compounds did not achieve Model Reach conditions in any zone, but all exhibited reductions in at least one zone.

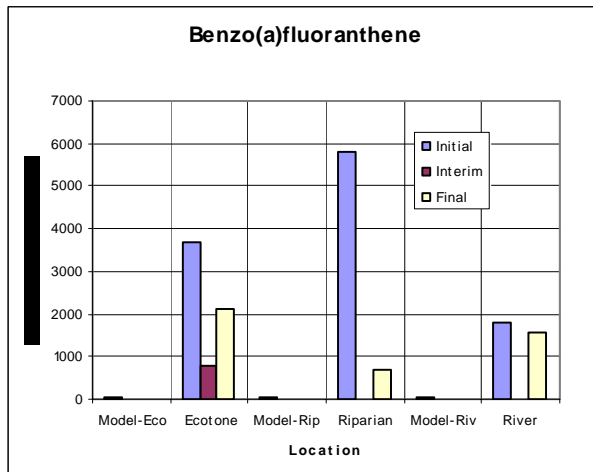
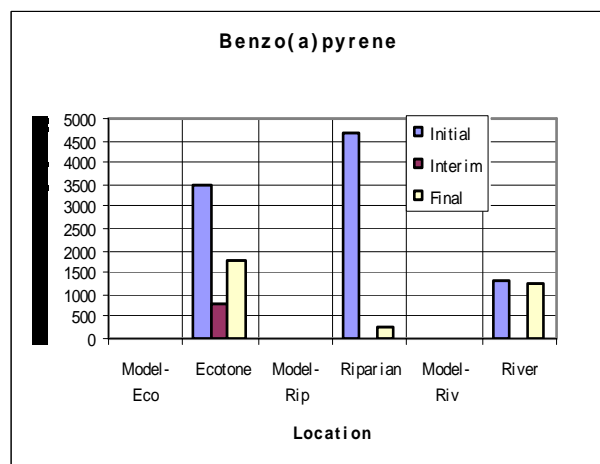
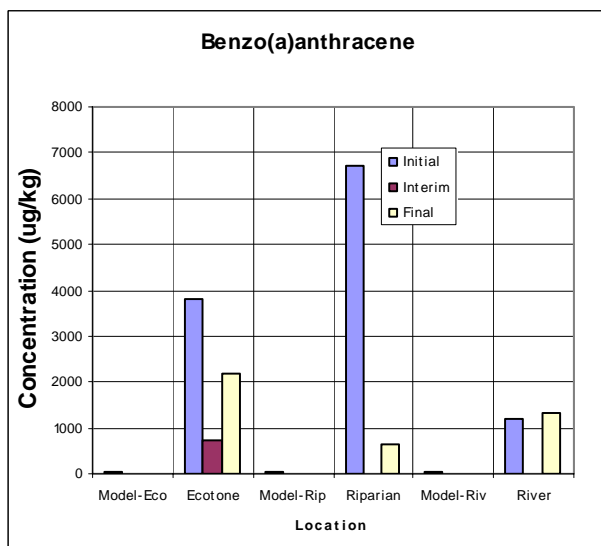
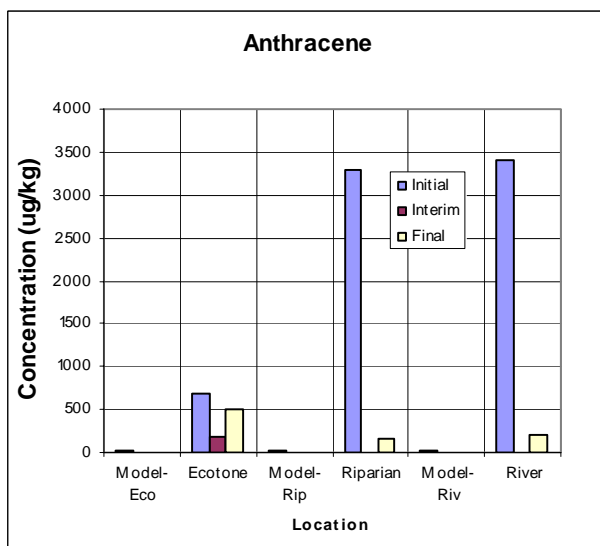
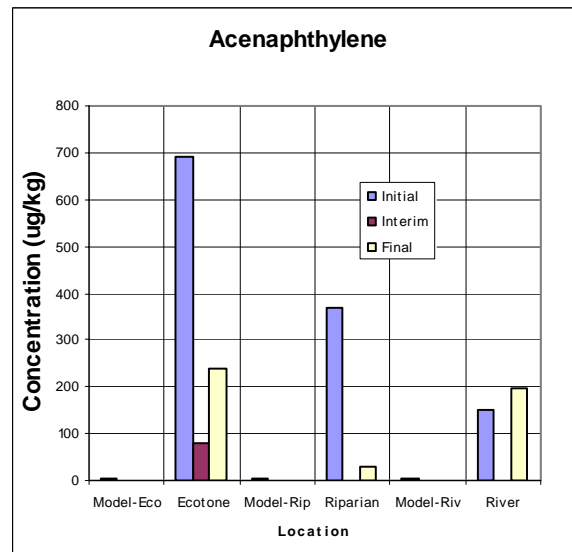
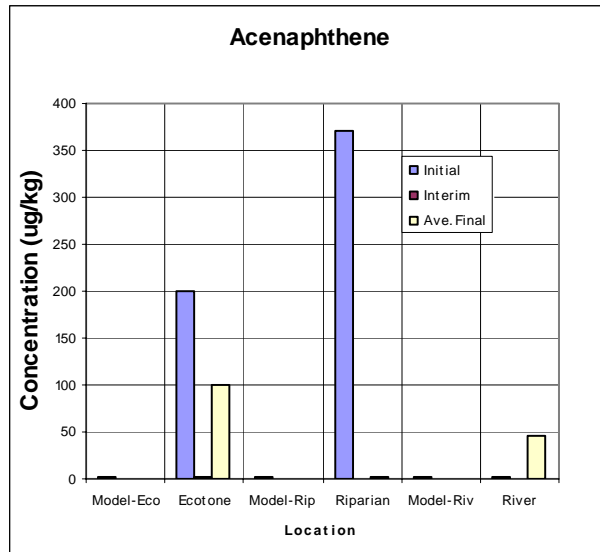
Table 9-1. Comparison of Leachable Metal Results to Model Reach

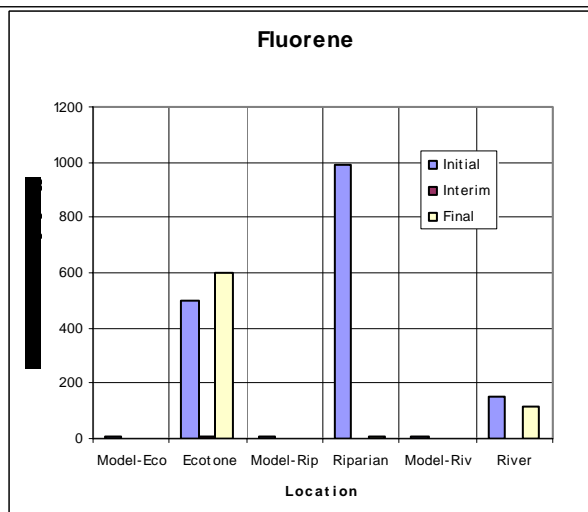
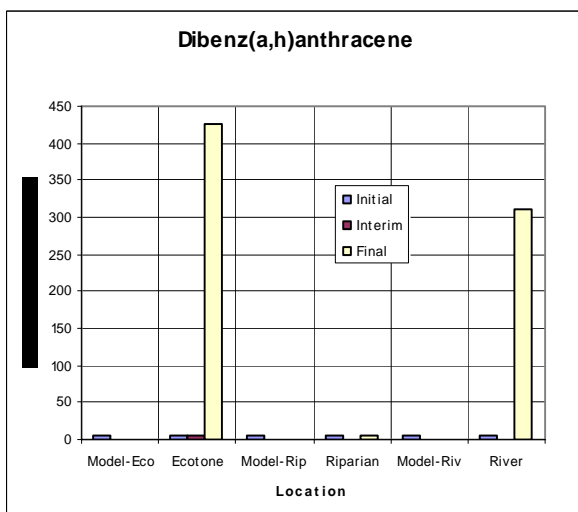
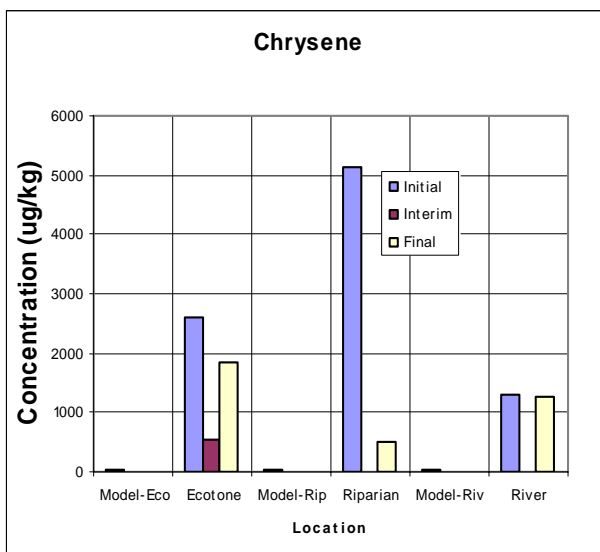
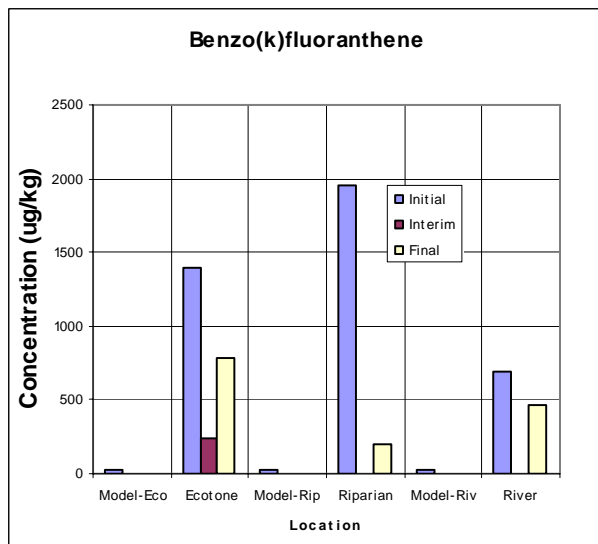
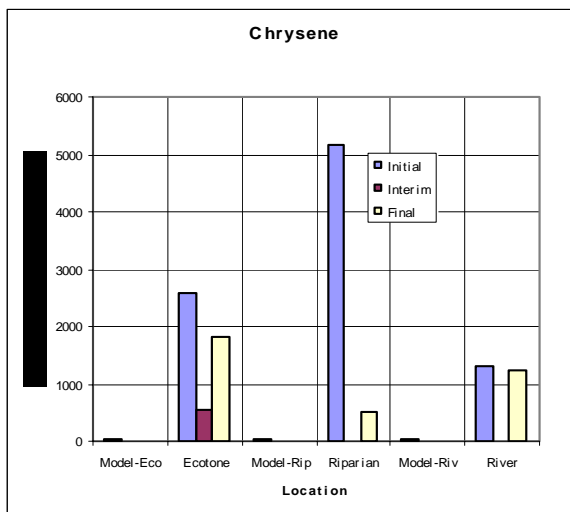
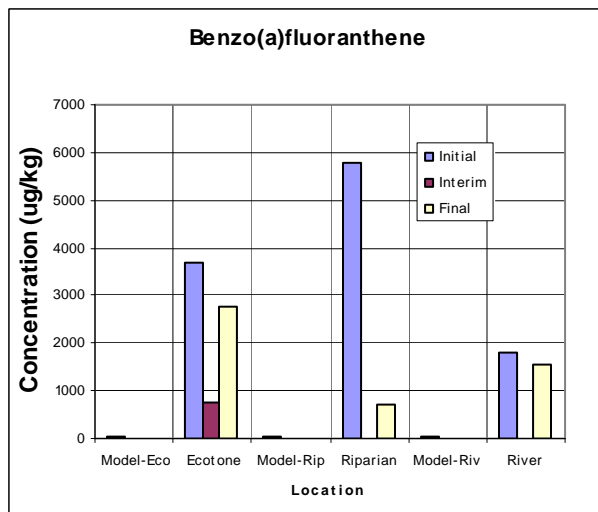
Analyte	Zone Location	Units	Model	Initial Sampling		Six Week Sampling			Final Sampling				Cleanup Achieved? (7,8,9,10)	Reduction WRT Initial? (7,8,9,11)
			Concentration (1,2,3)	Range	Average (1,3)	Range	Average (1,3)	Ave. as % Model (3,4,5)	Range	Average (1,3)	Ave. as % Model (3,4,5)	Ave. as % Reduction WRT Initial (3,4,6)		
arsenic	Overall	ug/L	<200	<200	<200	NA	NA	NA	170-<200	170	15%	NA	YES	NA
barium	Overall	ug/L	<1000	<1000-1050	1050	NA	NA	NA	840-1150	978	2%	4%	SOME	SOME
chromium	Overall	ug/L	<50	<50-361	361	NA	NA	NA	16-<50	16	68%	96%	YES	YES
iron	Overall	ug/L	15200	<1500- 1210000	1210000	NA	NA	NA	479000- 321625	321625	9046%	-7717%	NO	SOME
manganese	Overall	ug/L	2422	3540-20600	13213	7740	7740	-220%	1980- 21500	7821	-380%	40%	NO	YES
nickel	Overall	ug/L	<100	<100-608	378	NA	NA	NA	<100-851	363	-263%	-77%	NO	SOME
selenium	Overall	ug/L	<200	<200	<200	NA	NA	NA	110-<200	110	45%	NA	NA	NA
zinc	Overall	ug/L	879	<200-2480	2085	3790	3790	-331%	<200-8090	1976	-258%	-632%	NO	SOME

Notes:

1. BQL or Below Quantitation Limit (<) was not used in calculations where quantitative numbers exist.
2. Where BQL was the only result(s), the largest BQL was used in calculations.
3. BQL was not used to calculate average concentrations, but was used as the value for Model Reach.
4. Percentages were calculated individually for each zone and then averaged, so the percentage reduction/model may not match overall numbers.
5. Negative percentage in average concentration as a percent of Model Reach means that average concentration is above Model Reach concentration.
6. Negative percentage in Percent Reduction indicates an increase in average concentration rather than a decrease.
7. SOME means that at least one of the zones (river, ecotone, riparian) achieved cleanup or reductions for that analyte.
8. YES means that all zones achieved cleanup or reductions for that analyte.
9. NO means that none of the zones achieved cleanup or reductions for that analyte.
10. Cleanup Achieved means that treated area average concentration was below Model Reach concentration for that analyte.
11. Reduction WRT Initial means that the average treated concentration was reduced with respect to the initial concentration for that analyte.

Figure 9-4. Graphs Comparing PAH Results to Model Reach





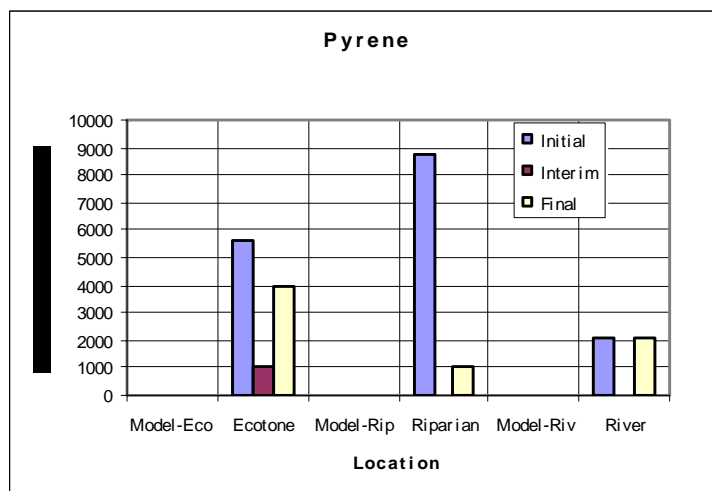
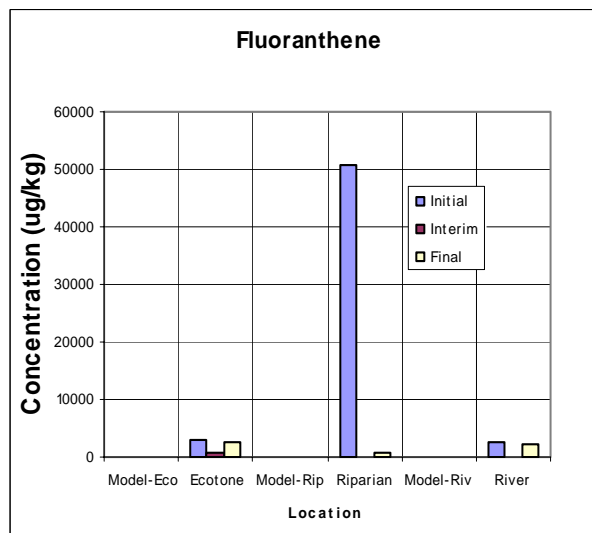
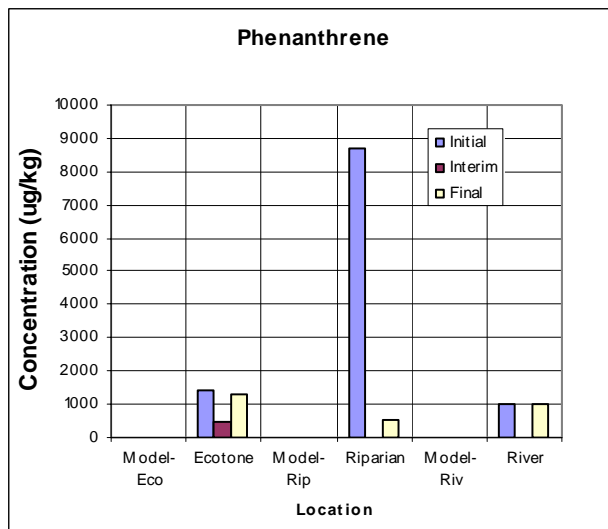
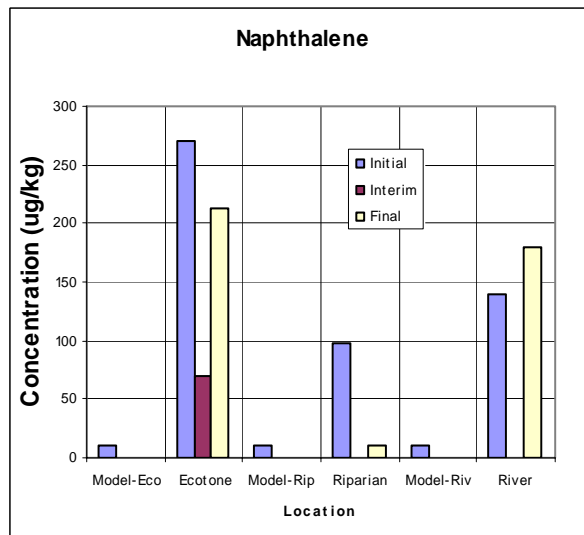
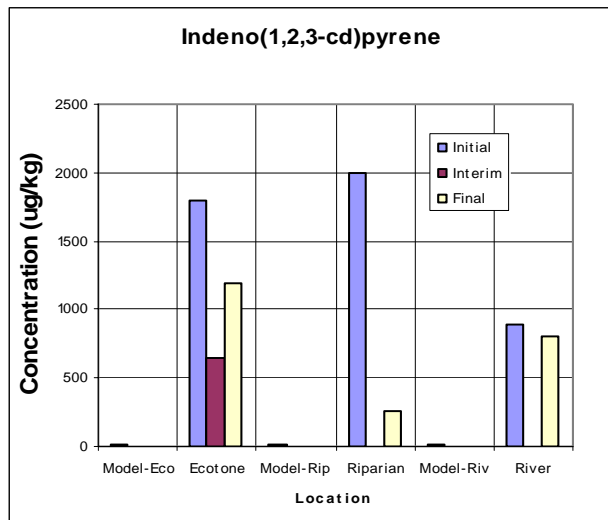


Table 9-2. Comparison of PAH Results to Model Reach

Analyte	Zone Location	Units	Model	Initial Sampling		Six Week Sampling			Final Sampling				Conclusions	
			Model Reach Concentration (1,2,3)	Range	Average (1,3)	Range	Average (1,3)	Ave. as % Model (3,4,5)	Range	Average (1,3)	Ave. as % Model (3,4,5)	Ave % Reduction WRT Initial (3,4,6)	Cleanup Achieved? (7,8,9,10)	Reduction WRT Initial? (7,8,9,11)
acenaphthene	Overall	ug/kg	<460	200-<4500	285	<600	<600	NA	100-<490	153	64%	43%	YES	YES
acenaphthylene	Overall	ug/kg	<460	150-<4500	377	52-110	81	80%	85-640	235	44%	55%	SOME	SOME
anthracene	Overall	ug/kg	<460	230-3400	1423	96-270	183	55%	160-<8200	316	27%	39%	SOME	YES
benzo(a)anthracene	Overall	ug/kg	<460	1200-6700	3900	420-1000	710	-73%	<430-4100	1500	-255%	61%	NO	SOME
benzo(a)pyrene	Overall	ug/kg	<460	1300-4800	3167	820	820	100%	39-<7500	1106	-159%	50%	SOME	YES
benzo(b)fluoranthene	Overall	ug/kg	<460	1800-6000	3767	430-1100	765	-87%	<422-<8200	1686	-297%	42%	NO	YES
benzo(ghi)perylene	Overall	ug/kg	<460	1000-2000	1550	170-490	330	20%	280-<8200	848	-99%	38%	SOME	YES
benzo(k)fluoranthene	Overall	ug/kg	<460	690-2000	1347	150-340	245	40%	200-<8200	480	-13%	56%	SOME	YES
chrysene	Overall	ug/kg	<460	1300-5200	3017	310-750	530	-29%	<425-2800	1199	-181%	41%	NO	YES
dibenz(a,h)anthracene	Overall	ug/kg	<460	<450-<4500	NA	<600	<600	NA	260-<8200	368	33%	69%	SOME	YES
fluoranthene	Overall	ug/kg	<460	1500-99800	20900	470-950	710	-73%	85-4700	1779	-315%	40%	NO	YES
fluorene	Overall	ug/kg	<460	150-1000	547	<600	<600	NA	88-<8200	366	2%	32%	SOME	SOME
indeno(1,2,3-cd)pyrene	Overall	ug/kg	<460	890-2000	1563	160-430	295	28%	260-<8200	773	-140%	42%	SOME	YES
naphthalene	Overall	ug/kg	<460	140-<4500	169	70-<600	70	83%	86-<8200	166	61%	18%	YES	YES
phenanthrene	Overall	ug/kg	<460	1000-9200	3717	230-560	395	4%	<420-<7500	936	-119%	51%	NO	SOME
pyrene	Overall	ug/kg	<460	2100-9300	5500	520-1500	1010	146%	<420-5600	2339	-452%	40%	NO	SOME

Notes:

1. BQL or Below Quantitation Limit (<) was not used in calculations where quantitative numbers exist.
2. Where BQL was the only result(s), the largest BQL was used in calculations.
3. BQL was not used to calculate average concentrations, but was used as the value for Model Reach.

4. Percentages were calculated individually for each zone and then averaged, so the percentage reduction/model may not match overall numbers.
5. Negative percentage in average concentration as a percent of Model Reach means that average concentration is above Model Reach concentration.
6. Negative percentage in Percent Reduction indicates an increase in average concentration rather than a decrease.
7. SOME means that at least one of the zones (river, ecotone, riparian) achieved cleanup or reductions for that analyte.
8. YES means that all zones achieved cleanup or reductions for that analyte.
9. NO means that none of the zones achieved cleanup or reductions for that analyte.
10. Cleanup Achieved means that treated area average concentration was below Model Reach concentration for that analyte.
11. Reduction WRT Initial means that the average treated concentration was reduced with respect to the initial concentration for that analyte.

9.3.4 TPH and Oil/Grease

Table 9-3 presents a comparison between the cleanup targets for TPHs in the Model Reach, the interim sampling results, and the final sampling results and those for oil/grease. Figure 9-5 is a graph illustrating this same comparison.

Discussion – TPH and oil/grease were two of the most prevalent contaminants in the river and shore sediments. Historically, microbes have been easily able to reduce these contaminants. This site, however, had numerous interferences from a wide variety of other contaminants. Nevertheless, oil and grease was reduced in all three zones in the Test Site, and TPH was significantly reduced (from 20,000 to 1260 mg/kg) in the ecotone of the Test Site, remained unchanged in the riparian zone, and actually increased in the river sediments. This increase is likely the result of re-contamination from upstream sediments in the river. The oil and grease detected in the river water samples only varied from 5.1 to 6.5 mg/L between the Model Reach and the interim sampling in the Test Site, not a significant difference.

Figure 9-5. Graph Comparing TPH and Oil/Grease Results to Model Reach

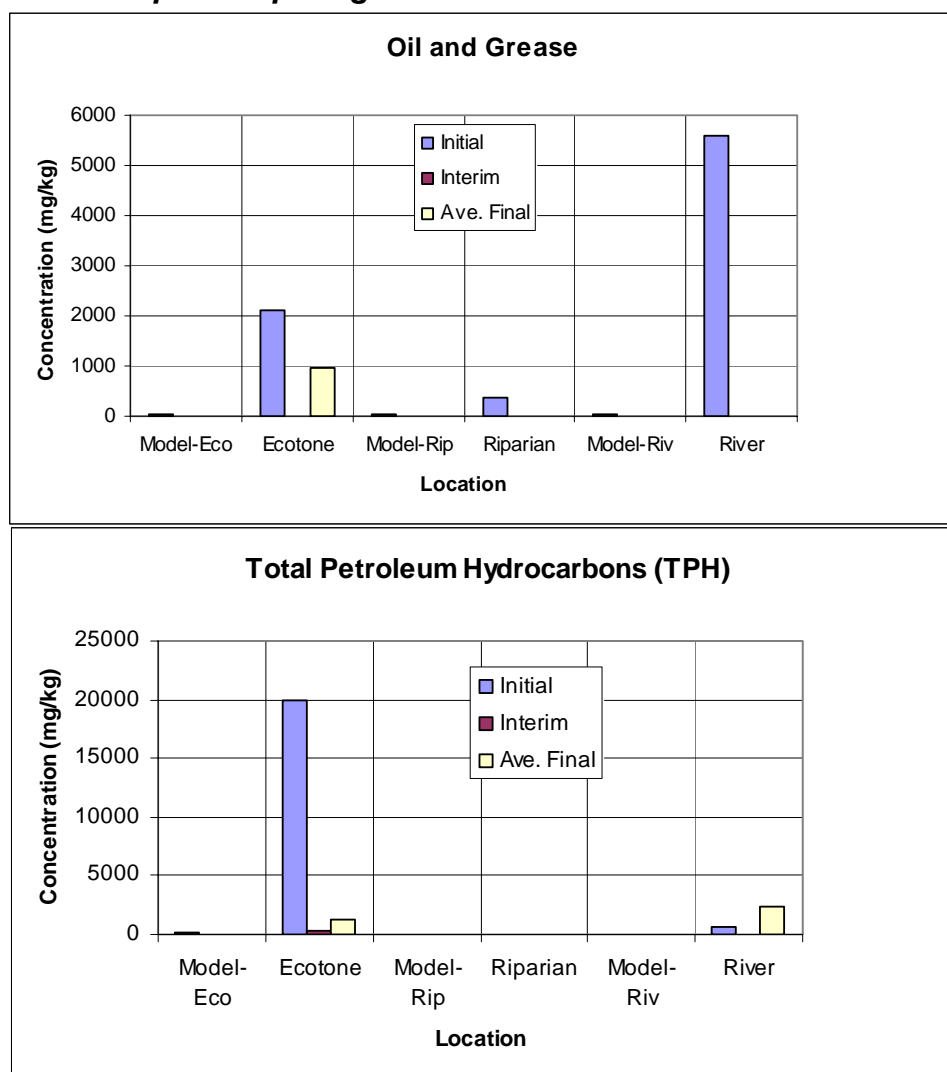


Table 9-3. Comparison of TPH and Oil/Grease Results to Model Reach

Analyte	Zone Location	Units	Model	Initial Sampling		Final Sampling				Conclusions	
			Concentration	Range	Average (1,3)	Range	Average (1,3)	Ave. as % Model (3,4,5)	Ave. as % Reduction WRT Initial (3,4,6)	Cleanup Achieved? (7,8,9,10)	Reduction WRT Initial? (7,8,9,11)
Oil & Grease	Overall	ug/kg	<330	360-5600	2687	950	950	-18.8%	64.6%	NO	YES
TPH	Overall	ug/kg	68.5	44-20000	6878	36-4600	1220	-1681	82.3%	NO	SOME

Notes:

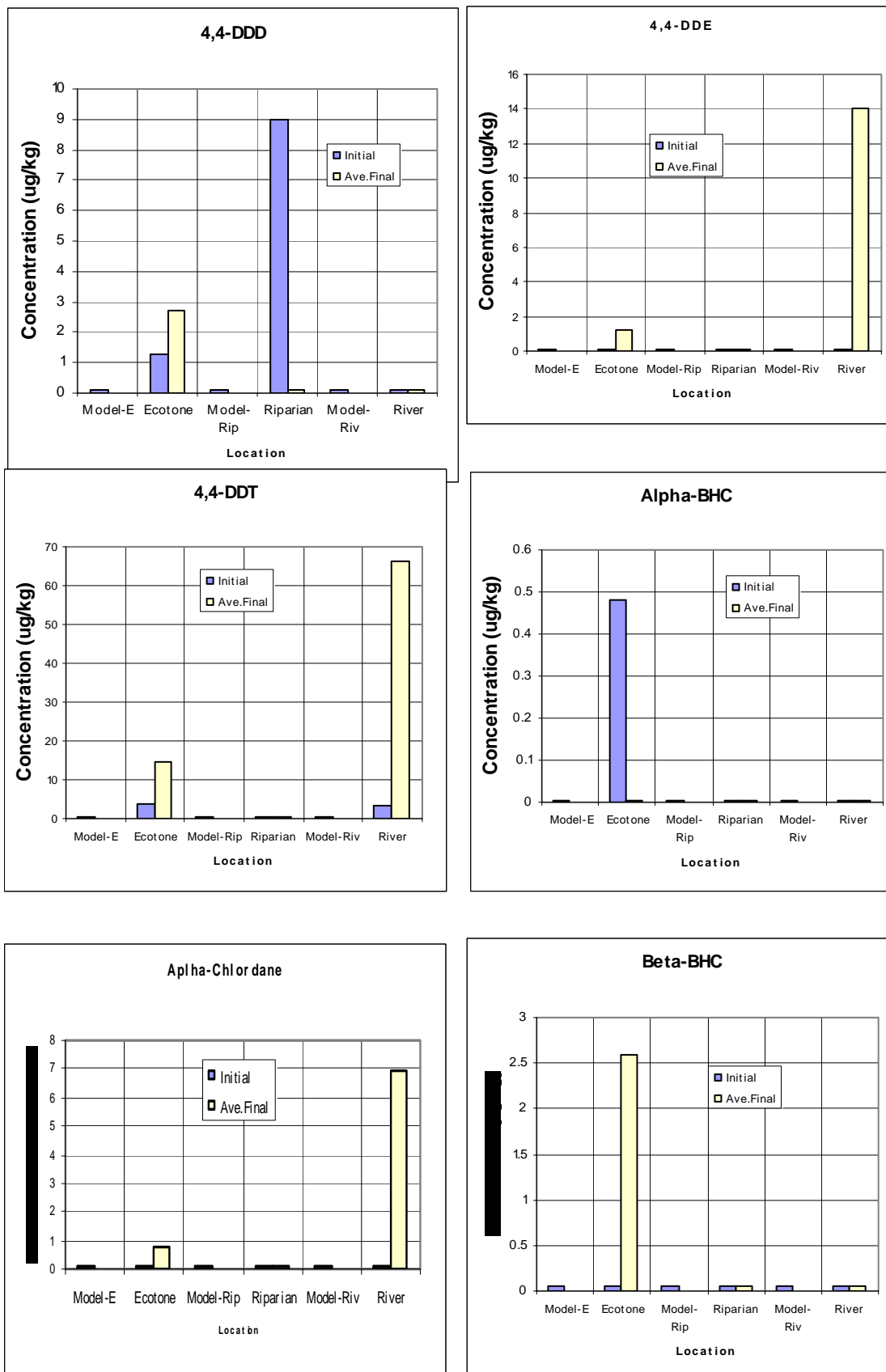
1. BQL or Below Quantitation Limit (<) was not used in calculations where quantitative numbers exist.
2. Where BQL was the only result(s), the largest BQL was used in calculations.
3. BQL was not used to calculate average concentrations, but was used as the value for Model Reach.
4. Percentages were calculated individually for each zone and then averaged, so the percentage reduction/model may not match overall numbers.
5. Negative percentage in average concentration as a percent of Model Reach means that average concentration is above Model Reach concentration.
6. Negative percentage in Percent Reduction indicates an increase in average concentration rather than a decrease.
7. SOME means that at least one of the zones (river, ecotone, riparian) achieved cleanup or reductions for that analyte.
8. YES means that all zones achieved cleanup or reductions for that analyte.
9. NO means that none of the zones achieved cleanup or reductions for that analyte.
10. Cleanup Achieved means that treated area average concentration was below Model Reach concentration for that analyte.
11. Reduction WRT Initial means that the average treated concentration was reduced with respect to the initial concentration for that analyte.

9.3.5 Pesticides

Table 9-4 presents a comparison between the cleanup targets for pesticides in the Model Reach, the interim sampling results, and the final sampling results. Figure 9-6 is a graph illustrating this same comparison.

Discussion – There were 12 pesticides detected in samples from the Test Site. Pesticides are of interest, even though they are not considered COCs, because they could adversely affect the consortium by poisoning the microbes designed to perform the degradation of other COCs. Therefore, we had to ensure that the pesticides were not at concentrations that would cause problems. Initial concentrations ranged from below detection to 30 ug/kg. Final concentrations ranged from below detection to 42.5 ug/kg, not a significant difference. Beta-BHC and gamma-chlordane achieved reductions in all three zones with respect to initial concentrations. Three other achieved reductions in at least one zone, while two did not exhibit reductions in any zone. It was not possible to make quantitative comparisons for four pesticides, alpha-BHC, endrin aldehyde, endosulfan sulfate, and methoxychlor, because final averages were below the detection limit. It can be concluded that most pesticides were detected at relatively low concentrations that hovered right around the detection limits. The analytical results exhibit numerous qualifiers, indicating estimated values and concentrations that are not reliably indicative of contamination. The only pesticides that were reported without qualification were in the DDD/DDT family, ranging from 7.6 to 87 ug/kg for six samples, all in the final sampling event. Four of these six results are the same order of magnitude as the detection limit. The most likely explanation for this is re-contamination by upstream contaminant sources. It appears that pesticides are not of concern, either from a health risk standpoint, or an ecological standpoint that would endanger the viability of the microbial consortium.

Figure 9-6. Graphs Comparing Pesticide Results to Model Reach



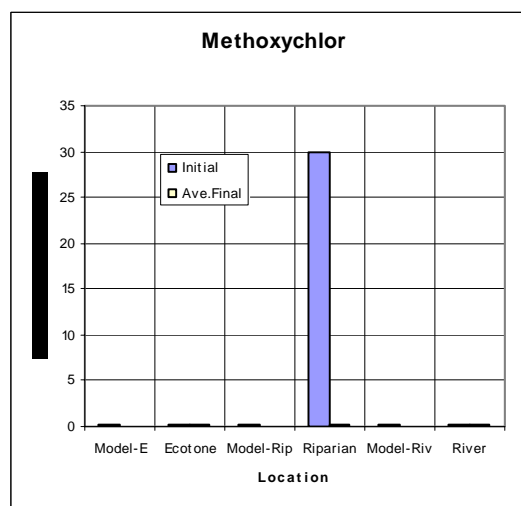
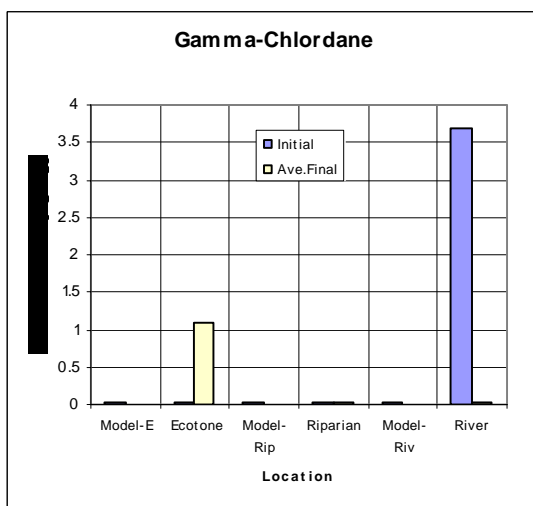
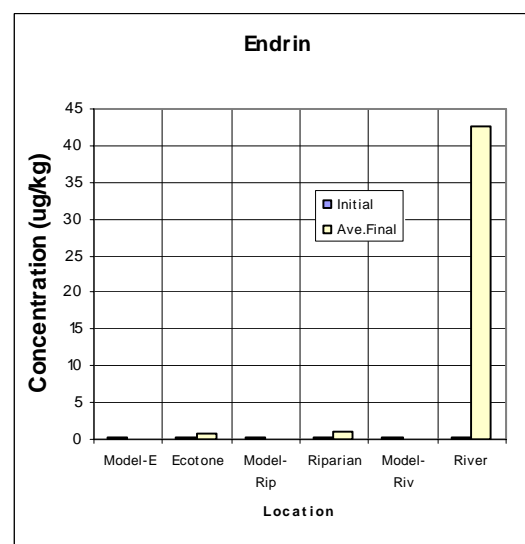
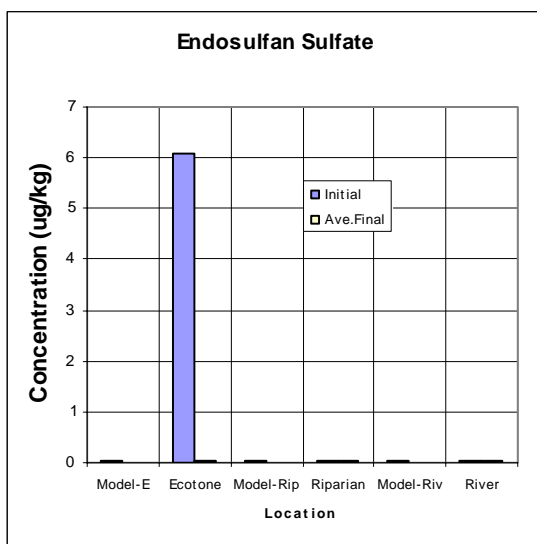
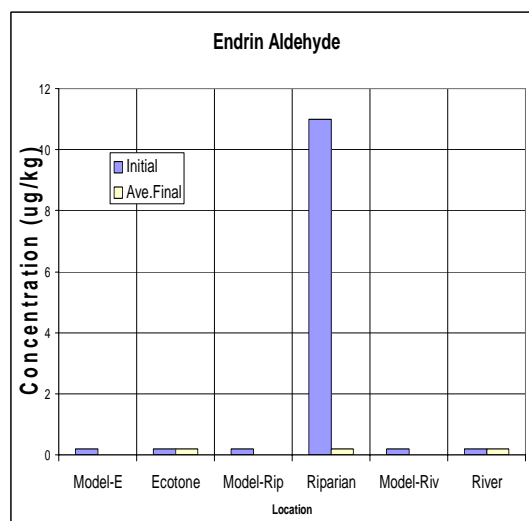
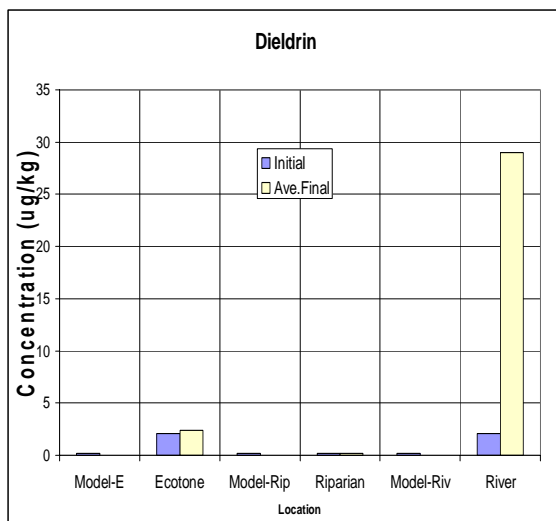


Table 9-4. Comparison of Pesticide Results to Model Reach

Analyte	Zone Location	Units	Model	Initial Sampling		Final Sampling				Conclusions	
			Model Concentration	Range	Average (1,3)	Range	Average (1,3)	Ave. as % Model (3,4,5)	Ave. as % Reduction WRT Initial (3,4,6)	Cleanup Achieved? (7,8,9,10)	Reduction WRT Initial? (7,8,9,11)
4,4-DDD	Overall	ug/kg	<2.3	1.3-9	5.2	<2.2-<47	<47	NA	NA	NA	NA
4,4'-DDE	Overall	ug/kg	<2.3	<2.3-<5.2	<5.2	1.8-<21	7.9	-247%	-64%	SOME	SOME
4,4'-DDT	Overall	ug/kg	<2.3	<2.1-3.6	3.4	<2.1-87	42.5	-1787%	-1196%	NO	NO
alpha-BHC	Overall	ug/kg	<2.3	0.48-<5.2	0.48	<2.2-<41	<41	NA	NA	NA	NA
alpha-chlordane	Overall	ug/kg	<2.3	<2.3-<5.2	<5.2	0.77-<41	3.8	-68%	21%	SOME	SOME
beta-BHC	Overall	ug/kg	<2.3	<2.3-<5.2	<5.2	<2.2-<41	2.6	-13%	16%	NA	YES
dieldrin	Overall	ug/kg	<2.3	2.1-<2.3	2.1	<2.2-24	12.1	-437%	-476%	NO	NO
endrin aldehyde	Overall	ug/kg	<2.3	<3.1-11	11	<2.2-<41	<41	NA	NA	NA	NA
endosulfan sulfate	Overall	ug/kg	<2.3	<2.3-6.1	6.1	<2.2-<41	<41	NA	NA	NA	NA
endrin	Overall	ug/kg	<2.3	<2.3-<5.2	<5.2	0.90-53	28.5	-549%	-198%	SOME	SOME
gamma-chlordane	Overall	ug/kg	<2.3	<2.3-3.7	3.7	1.1-<41	1.1	48%	65%	YES	YES
methoxychlor	Overall	ug/kg	<2.3	<3.1-30	30	<2.2-<41	<41	NA	NA	NA	NA

Notes:

1. BQL or Below Quantitation Limit (<) was not used in calculations where quantitative numbers exist.
2. Where BQL was the only result(s), the largest BQL was used in calculations.
3. BQL was not used to calculate average concentrations, but was used as the value for Model Reach.
4. Percentages were calculated individually for each zone and then averaged, so the percentage reduction/model may not match overall numbers.
5. Negative percentage in average concentration as a percent of Model Reach means that average concentration is above Model Reach concentration.
6. Negative percentage in Percent Reduction indicates an increase in average concentration rather than a decrease.
7. SOME means that at least one of the zones (river, ecotone, riparian) achieved cleanup or reductions for that analyte.
8. YES means that all zones achieved cleanup or reductions for that analyte.
9. NO means that none of the zones achieved cleanup or reductions for that analyte.
10. Cleanup Achieved means that treated area average concentration was below Model Reach concentration for that analyte.
11. Reduction WRT Initial means that the average treated concentration was reduced with respect to the initial concentration for that analyte.

SECTION 10.0 EVALUATION OF THE TECHNOLOGY

10.1 EVALUATION OF ENHANCED BIOREMEDIATION EFFECTIVENESS

This study demonstrated that bioremediation of the sediments associated with Mahoning River is both viable and feasible, but that conditions must be controlled to optimize its performance. When bioremediating a complex mixture of contaminants, one must set priorities regarding which are the most toxic and the most difficult to degrade. These must be addressed (degraded or detoxified) first. This can cause conflicts in cleaning for the first six to 12 months. As an example, reductive dechlorination will not bind out metals that require oxidation and the oxidation processes that reduce PAH's won't bind out metals that require a reducing environment. Very specific microbes and enzymes are required for each contaminant and metal. The result is that there will not be an equal reduction of everything in the first six months. It will take longer to achieve the model reach goals for all of the COC's. Nevertheless, the pre- and post-treatment sampling of the Test Site exhibited promising results for all COCs.

- Not every COC was reduced in every zone, but the overall trend was for reductions of most constituents in most zones of the Test Site.
- PAHs and PCBs were targeted most rigorously in the composition of the consortium, and consistent decreases in PAHs and intermediate transformations in PCBs were observed.
- The purchase of needed type cultures and enzymes was limited to remain within the allotted budget, so not all of the most effective ingredients could be included in the inoculum formulation. If more rigorous cultures had been made available, more dramatic results may have occurred over five months.
- The treatment was performed during the winter months, with low temperatures limiting the effectiveness of the consortium. More dramatic results could have been expected if inoculation was performed during the warmer months of the spring and summer.
- The evaluation period was limited to five months. Some COCs, particularly PCBs, are degraded in very complex processes, taking more time than is typically needed for bioremediation. Nevertheless, promising trends for most COCs were observed.
- Re-contamination from upstream will continue to compete with the cleanup until the upstream portions of the river are remediated.

10.2 RECOMMENDATIONS FOR TECHNOLOGY ENHANCEMENT

Although the technology's success was indicated by the COC reductions during the biotreatability feasibility study, there are way to improve the technique that were either not within the original scope, or were not funded by the original budget. To improve the performance of the technology for future applications, the following recommendation can be made:

1. **Allow a longer evaluation period.** WSI recommends that the Test Site be re-sampled in September 2004 to evaluate whether a longer time and warmer conditions will confirm continued cleanup.
2. **Sample more locations.** The sampling program, due to limited funds, could not collect enough samples to perform statistical analyses on the results. Neither could the program identify the likelihood of how spatial variability could impact the

- evaluation results because many comparisons were relying on too few data points. A more rigorous sampling program would yield more reliable and clearer results and WSI recommends any continued evaluation include more comprehensive sampling.
3. **Include more type cultures and enzymes.** The suite of type cultures and enzymes was limited in order to stay within the budget allotted for the project. Thus, many of the enzymes needed in the consortium for optimal biodegradation were not purchased, but had to be grown by other microbes. Also many of the microbe type cultures needed to increase the viability of the indigenous microbes used were not used. These two factors may have limited the effectiveness of the consortium for some constituents. If future work is considered, additional type cultures and enzymes should be budgeted.
 4. **Perform another database search before additional work.** Additional microbes constantly are being identified that could degrade some of the more recalcitrant compounds. Research in the field results in published papers that uncover additional functions for a variety of micro-organisms. If future inoculation is considered, research must be performed to ensure that the consortium is up-to-date with current research results.
 5. **Consider re-inoculating the hot spots.** The consortium has been kept viable for the duration of the study and is still maintained. If some spots need to be treated again to encourage a faster response, most of the work and expense has already been expended. This is particularly true if later sampling still uncovers some recalcitrant compounds. WSI recommends maintaining the cultures until a final decision on the feasibility of bioremediation or limited re-inoculation is made.
 6. **Application Optimization Study.** This study tested the technology, but did not test the difference between application methods. As stated in #5 above, re-growing the inoculum for another feasibility study could be accomplished very cost-effectively, since most of the work is already done. WSI recommends another small study to test different application rates and methods, so the best combination of technology and application can be applied to a larger-scale remedy.
 7. **Treat upstream first.** This will minimize the likelihood of re-contamination of the downstream portions of the river.

SECTION 11.0 LARGE-SCALE APPLICATION OF THE TECHNOLOGY

Bioremediation is being considered as one potential remedy to address the contamination in the sediments in the river and along the banks of the Mahoning River. The remedy(s) that is selected must be capable of treating all COCs to concentrations that are at or below Model Reach conditions. The remedy also must be able to treat buried bank deposits and submerged river sediments. Finally, the remedy should minimize disturbance to the existing environment and ecosystem, particularly the vegetation along the banks of the river.

11.1 CONSIDERATIONS FOR LARGE-SCALE APPLICATION

Large-scale application of any treatment technology requires treating 31 miles of river, 462,000 cubic yards of river sediments, and 286,000 cubic yards of bank sediments. Dredging can remove the majority of contamination in the river sediments, but does not address bank sediments and can leave the river channel devoid of beneficial microbes needed for the health of the river, while leaving significant concentrations of contaminants behind.

As compared to more aggressive treatments, bioremediation is a long-term, passive remedy that can be applied successfully either to portions of the river system, or to the entire length of the study area. Its advantages are: 1) it is relatively non-invasive and beneficial to the site ecology, 2) it will continue to work as long as there is contamination serving as a food source, 3) there is no equipment or maintenance required after inoculation, and 4) it can be coupled with other, more aggressive remedies, either to address “hot spots” or as a finishing step after dredging.

It should be noted that in this discussion of the potential for large-scale application and in the following section on cost estimates, the particular methods, benefits, and costs are associated with Lambda's proprietary technology. The application of other bioremediation technologies may be quite different and the results of this study cannot be used to judge their potential effectiveness, feasibility, or cost. The research that went into the formulation of this consortium can be applied to any follow-on work, for the relatively modest additional cost of updating the consortium. Whether one gallon or one million gallons of consortium are needed in the future, most of the research for the formulation has already been completed.

Several factors must be considered in a full-scale application. The major ones are listed below.

1. **Combining Remedies.** Based on the results of this biotreatability study, WSI recommends a combination of technologies for optimal results. Some areas of the site that are severely contaminated should be considered candidates for excavation or dredging, with a bioremediation applied after the majority of the contaminants are removed to help re-establish the ecosystem. Due to the ambiguous results in this study relative to the river sediments, WSI recommends that Eastgate and USACE consider dredging the near-shore river sediments rather than exclusively using bioremediation. Bioremediation appears to be most suitable for on-shore sediments. Regardless, upstream cleanup should be enacted first to minimize downstream re-contamination during cleanup.
2. **Large-Scale Application.** WSI sees no real advantage in applying bioremediation on a reach-by-reach basis, other than perhaps a logistical one. This may change once the full characterization of the existing conditions of the river have been studied. Factors that could affect this decision are obvious and significant physical or chemical differences between the reaches that are identified. However, the upstream portion of the river should be addressed first to minimize the likelihood of re-contamination.
3. **Combining COC-Specific Remedies.** WSI believes that bioremediation can address all COCs at the site and, since it is our understanding that no one type of COC is found apart from the others, there is no reason to apply different remedies to different COCs.

4. **Sediment Spatial or Textural Variability.** Like any remedy that relies on subsurface migration, bioremediation will be more effective in some soils than others. Generally, it is only a matter of time until the treatment reaches the contamination. Once it is introduced into the subsurface, it can migrate to the contamination in several ways. First, it can migrate under hydraulic forces that cause the fluid to move under the forces of gravity and capillary action. Repeated, post-inoculation applications of fluids, such as the infiltration of rain water, will drive the consortium deeper under hydraulic head differentials. Second, the microorganisms, themselves, are mobile and will propagate in the subsurface. They will move to where there is a food source (contamination). Both of these mechanisms depend, to a large extent, on the saturation and hydraulic conductivity (permeability) of the soils. More permeable soils will exhibit a faster response to treatment than finer-textured soils (clays). There was some clay encountered at the Test Site, and treatment can be expedited by subsurface injection rather than surface application.
5. **Application Methods.** As discussed in the following section, there are several methods of applying the inoculum to the site. These are: 1) surface spraying (with or without pressure), 2) injection, and 3) BioCarb bags. There also are different site preparation methods that can be used to expedite the movement of the inoculum to the contamination, including tilling the soils, injection in pre-drilled holes, pressure injection in shallow sediments, flooding, among other variations. Tilling and subsurface injection will introduce the treatment deeper into the soils, thus allowing the microbes to attack the deeper contamination more quickly. WSI has recommended an engineering optimization study to determine the application method that best suits each requirement of the site, while considering cost realism.
6. **Logistical Considerations.** Moving large amounts of inoculum from the laboratory to the site will require tanker trucks for transport. These trucks will be necessary even if a temporary laboratory is established in the Youngstown area (which would reduce transportation costs). Moving the inoculum from the transport vehicle to where it is needed along the river can be done most effectively from the water, and WSI anticipates large-scale inoculation would be conducted from a boat. If injection is required, this will have to be done on foot. It is absolutely imperative that inoculation take place in the spring before the vegetation begins to leaf, but after the temperatures begin to warm. This leaves perhaps a month to inoculate the site, preferably the month of April. Once the leaf cover thickens, surface application will have a difficult time reaching the soil surface, and will tend to remain on the surface of the vegetation. If it is found that soil preparation, such as tilling or drilling, is required (from the application optimization study), the site can be prepared the month prior to inoculation.

It is anticipated that two 400-gallon tanks can be mounted on a motorized boat and that a 20-ft wide swath of bank on either side of the river can be inoculated, one side as the boat travels up-stream and the other side as the boat travels downstream. River sediments can be inoculated using a separate boat and tank, using the pressurized injection wand, perhaps followed by placement of BioCarb™ bags. Section 11.2 discusses the logistics, assumptions, and costs of different remediation scenarios.

7. **Application Rates.** An application rate of nearly 7000 gallons per acre was used at the Test Site. The effectiveness of the technology depends on application rate, formulation, and length of time allowed to work. The application rate was triple of that typically used

when applying this technology. It is believed that the recommended application rate of approximately 2000 gallons per acre for large scale cleanup will be effective for the following reasons: a) past experience at over 150 other sites has confirmed this application rate, b) cleanup upstream portions of the site first will allow the cleanup to proceed without competing with contaminants that re-contaminate the site, c) a longer duration cleanup will more effectively clean the site, and d) inoculation during warm weather will allow the microbes to establish an active community before cold weather and inactivity sets in.

8. **Site Disturbance.** Pre-drilling holes may be necessary in areas where contamination is below five feet. This will speed the migration of the microbes to the deeper parts of the site. Some vegetation clear may be necessary for access to certain areas of the site. WSI does not recommend wide-scale vegetation clearing, as the phytoremediation that can take place during the bioremediation is valuable to the overall cleanup and the balance of the ecosystem will be better maintained with the indigenous vegetation present. Also, vegetation will discourage the erosion of the bank soils. As a result, at some limited locations, bioremediation may require the application of some invasive technologies, such as drilling, soil tilling, and vegetation clearing.
9. **Other Benefits of Bioremediation.** Besides cleaning the COCs with minimal negative impact to the ecosystem, bioremediation has several other potential benefits. The inoculum is full of soil nutrients and will benefit vegetation where it is applied. Bioremediation can be used in conjunction with other remedies, to reduce the waste that is generated. The same inoculum that is applied to the banks of the river can be mixed with any river dredgings to treat them and convert them to a beneficial use material that can be used in a variety of ways, such as cover, capping material, soil amendment, etc. Additional studies would be needed to demonstrate this application before it is used.

11.2 ESTIMATION OF COSTS

A cost estimate was prepared to allow the comparison of bioremediation to other technologies and to provide an estimate of the overall cost for full-scale application to the river system. The costs of remediating each unit are regardless of whether it is coupled with another technology, such as dredging. In addition to the assumptions listed below, the cost backup in Appendix D describes some of the uncertainties at this stage that led to the application of a +/-30% range. The uncertainties include the preliminary nature of engineering data, such as physical access along the 31-mile length of riverbank (road access, slopes, density of vegetation, presence of ground cover such as leaf litter), actual depth and lateral extent of contaminants to be treated, and optimized application methods (recommended for study, as described in Sections 10.2 and 11.1).

These cost estimates are applicable to this particular proprietary technology and do not apply to other bioremediation technologies. The costs reflect the fact that most of the research has already been done during the treatability study and would only have to be updated for large-scale applications, at a relatively minor cost. The cost of this update is included in the unit prices.

The following assumptions were used to prepare the cost estimates:

Major assumptions for bank areas

1. Assumed average width of treatment area on each bank is 20 feet, with actual width to be determined based on characterization studies by others.
2. Inoculum is assumed to be applied by pressure spraying onto surface and injecting into pre-driven/drilled holes.
3. Total average application rate is assumed at 2000 gal/acre, approximately one-third of the Test Site rate. The higher rate was used at Test Site to accelerate remediation and demonstrate results within the limited contract period.
4. Assumed depth of treatment is average 6 feet on banks, utilizing subsurface injection and surface spraying.
5. Confirmatory or effectiveness sampling and other cost components common to other remediation technologies are not included.

Major assumptions for river areas

1. Assumed average width of treatment area is 20 feet into river from each bank, with actual width to be determined based on characterization studies by others.
2. BioCarb bags saturated with inoculum are assumed to be placed at 20-foot intervals in the river.
3. Additional inoculum is assumed to be injected into sediments between bags.
4. Assumed depth of treatment is average two feet in river sediments.
5. Confirmatory or effectiveness sampling and other cost components common to other remediation technologies are not included.

Table 12-1. Unit Costs for Full-Scale Implementation of Bioremediation on the Mahoning River

Remedial Scenario	Estimated Cost per River Mile	Estimated Cost per Cubic Yard (CY)
Enhanced bioremediation of bank sediments only	\$202,000 - \$375,000	\$4.30 - \$8.00
Enhanced bioremediation of bank sediments and river sediments	\$374,000 - \$690,000	\$5.95 - \$11.10

Ranges represent +/-30% of estimated cost. Does not include effectiveness sampling.

A cost range is presented, which represents our best estimate plus or minus 30%, appropriate to the preliminary nature of engineering data available at this stage. It is anticipated that the duration of the treatment will be a minimum of two years, although results should be measurable within six months and cleanup will continue beyond the two-year period.

A cost estimate was prepared to allow the comparison of bioremediation to other technologies and to provide an estimate of the overall cost for full-scale application to the river system. The costs of remediating each unit is regardless of whether it is coupled with another technology,

such as dredging. Costs for monitoring the effectiveness of this or a combination of remedies were not included, as this will be common to all technologies, and should not be considered in a comparison. Details of this cost estimate are included as Appendix D of this report.

SECTION 12.0 REFERENCES

- 3rd edition, HHS Publication No. (CDC) 93-8395, US Department of Health and Human Services, Centers for Disease Control and Prevention, US Government Printing Office, Washington, DC, 1993.
- Atlas, Ronald M. *Handbook of Media for Environmental Microbiology*, CRC Press, Inc., 1995.
- Baker, Katherine H., and Diane S. Herson, eds. *Bioremediation*, McGraw-Hill, Inc., 1994.
- Cookson, John T. *Bioremediation Engineering: Design and Application*, McGraw-Hill, Inc., 1995.
- Cotton, F. Albert, and Geoffrey Wilkinson. *Advanced Inorganic Chemistry, A Comprehensive Text, Second Revised and Augmented Edition*, John Wiley & Sons, Inc., 1966.
- Donahue, Roy L., Raymond W. Miller, and John C. Shickluna. *Soils, An Introduction to Soils and Plant Growth, Fifth Edition*, Prentice-Hall, Inc., 1983.
- Ehrlich, Henry Lutz. *Geomicrobiology, Third Edition*, Marcel Dekker, Inc., 1996.
- Gibson, David T. *Microbial Degradation of Organic Compounds*, Marcel Dekker, Inc., 1984.
- Hawksworth, D.L., P.M. Kirk, B.C. Sutton, and D.N Pegler, Ainsworth & Bisby's *Dictionary of the Fungi, Eighth Edition*, CAB International, 1995.
- Hawley, Gessner G. *The Condensed Chemical Dictionary, Tenth Edition*, Van Nostrand Reinhold Company, 1981.
- Krumbein, W.E. *Microbial Geochemistry*, Blackwell Scientific Publications, 1983.
- Lane, A.L. *DIFCO Manual, 10th Edition*, DIFCO Laboratories, Detroit MI, 1984.
- McDonald, Donald, et al. *Skills & Knowledge of Cost Engineering, Third Edition, Revised*, Association for the Advancement of Cost Engineering, 1992.
- Merck & Co., Inc., *The Merck Index, 11th Edition*, 1989.
- Ney, Ronald E. *Fate and Transport of Organic Chemicals in the Environment: A Practical Guide, 2nd Edition*, Government Institutes, 1995.
- Ohio Environmental Protection Agency (OEPA). *Biological and Water Quality Study of the Mahoning River Basin*. OEPA Technical Report MAS/1995-12-14, May 1, 1996.

Patterson, David J. *Free-Living Freshwater Protozoa: A Colour Guide*, John Wiley & Sons, Inc., 1996.

Robichaud, Cliff, ed. *Water Supply and Pollution Control, Fourth Edition*, Harper Collins Publishers, Inc., 1985.

Shaw, A. Jonathan, ed. *Heavy Metal Tolerance in Plants: Evolutionary Aspects*, CRC Press, Inc., 1989.

South, G. Robin. *Introduction to Phycology*, Blackwell Scientific Publications, 1987.

Stanier, Roger Y., Michael Doudoroff, and Edward A. Adelberg, *The Microbial World, Second Edition*, Prentice-Hall, Inc., 1963.

Stoner, Daphne L., ed. *Biotechnology for the Treatment of Hazardous Waste*, CRC Press, Inc., 1993.

Uhlir, Helmut. *Industrial Enzymes and their Applications*, John Wiley & Sons, Inc., 1998.

Volesky, Bohumil, ed. *Biosorption of Heavy Metals*, CRC Press, Inc., 1990.

Mahoning River Biotreatability Study
Final Report
July 2004

TABLE OF CONTENTS

<i>Section</i>	<i>Page</i>
SECTION 1.0 BACKGROUND AND OBJECTIVES	1
EXECUTIVE SUMMARY	1
1.1 Overall Restoration Objectives	2
1.2 Project Description and Background	2
1.3 Biotreatability Study Objectives	3
SECTION 2.0 DESCRIPTION OF THE TET SITE	3
2.1 Physical Description	3
2.2 Contaminants of Concern	4
SECTION 3.0 DESCRIPTION OF THE TECHNOLOGY	6
3.1 Ecological Balance	6
3.2 Mahoning River Ecosystem	6
3.3 Feasibility for Test Site Remediation	7
SECTION 4.0 QUALITY ASSURANCE AND QUALITY CONTROL	9
SECTION 5.0 HEALTH AND SAFETY	11
SECTION 6.0 FIELD SAMPLING	11
6.1 Initial Sampling Design	12
6.1.1 Model Reach and Recovering Area Sites	13
6.1.2 Test Site	13
6.2 Six Week (Interim) Sampling	13
6.3 Final Sampling	14
6.4 Field Measurements	14
SECTION 7.0 LABORATORY TESTING	16
7.1 Chemical Analyses	16
7.1.1 Laboratory Methods and Protocol	16
7.1.2 Summary of Findings	16
7.1.3 Analytical Data Quality Discussion	21
7.2 Biological Analyses	43
7.2.1 BioScan™	43
7.2.2 MicroEcological Profile™	44
7.2.3 Summary of Findings	50

<i>Section</i>	<i>Page</i>
SECTION 8.0 CONSORTIUM FORMULATION AND INOCULATION	50
8.1 Acclimation	51
8.2 Scale-Up	52
8.3 Test Site Inoculation	53
SECTION 9.0 EFFECTIVENESS SAMPLING	58
9.1 Cleanup Targets	58
9.2 Data Limitations	58
9.3 Analytical Conclusions	59
9.3.1 PCBs	60
9.3.2 Leachable Metals	63
9.3.3 PAHs	65
9.3.4 TPH and Oil/Grease	72
9.3.5 Pesticides	74
SECTION 10.0 EVALUATION OF THE TECHNOLOGY	78
10.1 Evaluation of Enhanced Bioremediation Effectiveness	78
10.2 Recommendations for Technology Enhancement	78
SECTION 11.0 LARGE-SCALE APPLICATION OF THE TECHNOLOGY	79
11.1 Considerations for Large-Scale Application	80
11.2 Estimation of Costs	82
SECTION 12.0 REFERENCES	84

LIST OF FIGURES

<i>Figure</i>	<i>Page</i>
2-1 Topographic Map of the Test Site Area	4
2-2 Aerial Photograph of the Test Site	5
3-1 Schematic of Bioremediation of PCB Aroclors	10
6-1 All Sampling Locations	15
7-1 Lambda Staff Preparing Growth Media for MicroEcological Profile™	47
7-2 View of the Growth Media and Nutrient Collection at Lambda's Laboratory	47
8-1 The Acclimation Process	51
8-2 The Acclimation Process with Growth Tank in the Background	52
8-3 Test Site Prior to Grubbing	53
8-4 Configuration of the Inoculation Layout	55
8-5 Schematic of the Inoculation of the Test Site	55
8-6 Inoculation of the River Zone	56
8-7 Inoculation of the Ecotone	57
8-8 Inoculation of the Riparian Zone	57
9-1 Comparative Concentrations of Aroclor 1232, 1254, and	61
9-2 1260PCB Sampling Summary	62
9-3 Graphs Comparing Leachable Metal Results to Model Reach	64
9-4 Graphs Comparing PAH Results to Model Reach	67
9-5 Graphs Comparing TPH and Oil/Grease Results to Model Reach	72
9-6 Graphs Comparing Pesticide Results to Model Reach	75
12.1 Unit Costs for the Full-Scale Implementation of Bioremediation on the Mahoning River	82

LIST OF TABLES

<i>Table</i>	<i>Page</i>
6-1. Field Measurements Taken During Sampling at Test Site	15
7-1 Total TPH, PAH and Pesticide Reductions	16
7-2 Data Qualifier Definitions and Significance	17
7-3 General Chemistry Summary	21
7-4 Oil & Grease and Total Petroleum Hydrocarbons (TPH) Summary	25
7-5 Polychlorinated Biphenyl (PCB) Summary	26
7-6 Pesticides Summary	28
7-7 TCLP Metals Summary	32
7-8 Polycyclic Aromatic Hydrocarbons (PAHs) Summary	35
7-9 DIFCO Industrial Microbial Scale	44
7-10 Results of the BioScan™ for the Mahoning River	45
7-11 Results of the MicroEcological Profile™ for the Mahoning River	48
9-1 Comparison of Leachable Metals Results to Model Reach	66
9-2 Comparison of PAH Results to Model Reach	70
9-3 Comparison of TPH and Oil/Grease Results to Model Reach	73
9-4 Comparison of Pesticide Results to Model Reach	77
12-1 Unit Costs for Full-Scale Implementation of Bioremediation on the Mahoning River	83

LIST OF APPENDICES

Appendix A – Comprehensive Analytical Results and Analytical Methods
Appendix B – Location of Sampling in Model Reach and Recovering Areas
Appendix C – Field Notes and Field Data Sheets
Appendix D – Cost Estimate Details
Appendix E – Ohio EPA Permit to Construct
Appendix F – DrChecks Comments on Draft Plans
Appendix G – DrChecks Comments on Draft Final Report

Glossary of Acronyms and Selected Terms

Aroclor – commercial name for various blends of PCBs
TALs – Total Analyte List Metals
BQL – Below Quantitation Limits
COCs – Contaminants of Concern
DO – Dissolved Oxygen
DUP – Duplicate sample
Ecotone – That area along the river bank from the edge of the water to the normal high water mark
FSP – Field Sampling Plan
GC – Gas chromatograph
GPL – GPL Laboratories
Lambda – Lambda bioremediation Systems, Inc.
MEP – Microecological Profile™
mg/kg and ug/kg – Milligram and microgram per kilogram
mg/L and ug/L – Milligram and microgram per liter
OEPA – Ohio Environmental Protection Agency
PAHs – Polycyclic Aromatic Hydrocarbons
PCBs – Polychlorinated Biphenyls
QA – Quality Assurance
QAPP – Quality Assurance Project Plan
QC – Quality Control
RCRA – Resource Conservation and Recovery Act
REDOX – Oxidation-Reduction Potential
Riparian – that area along the river bank of greater elevation than the ecotone, but within the floodplain
SAHP – Safety and Health Plan
TCLP – Toxicity Characteristic Leaching Procedure
TKN – Total Kjeldahl Nitrogen
TOC – Total Organic Carbon
TOP – Total Organic Phosphorus
TPH – Total Petroleum Hydrocarbons
USACE – US Army Corps of Engineers
WSI – Waste Science Inc.

APPENDICES

Appendix A – Comprehensive Analytical Results

Appendix B – Field Notes and Field Data Sheets

Appendix C – Cost Estimate Details

Appendix D – Ohio EPA Permit to Construct

Appendix E – Review Comments on Draft Plans

Appendix F – Review Comments on Draft Final Report

Final Report

Biotreatability Study Mahoning River

Prepared by:
Waste Science Inc.

Prepared for:
Eastgate Regional Council of Governments and
US Army Corps of Engineers – Pittsburgh District



EASTGATE
Regional Council of Governments



July 2004

**G-221-RD-10
Rev. 01**